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CARBON RATIOS AS AN INDEX OF OIL AND GAS IN WESTERN CANADA.

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INTRODUCTION.

THE petroleum possibilities of the provinces of Alberta and Saskatchewan in western Canada are receiving considerable attention. This region contains large and widespread reserves of coal of nearly all ranks and, therefore, it is desirable to determine if they can be used as an index to the regional metamorphism of the enclosing sediments. The area offers an excellent opportunity to test whether such a relation exists. The western portion is in the Rocky Mountains and the eastern in the Great Plains, with transitional features between them. That is, the area extends from a region of great deformation and intense metamorphism to one where disturbance and attendant rock alteration have been comparatively small.

The writer wishes to show that in western Canada the fixed carbon content of coals cannot be used to measure the regional dynamic metamorphism, nor can it serve as an index to possible oil and gas accumulations.

THE CARBON RATIO THEORY.

David White in 1915 [1] advanced the hypothesis which has since become well-known as the "carbon ratio theory." He pointed

[1] White, D., "Some Relations in Origin between Coal and Petroleum," *Jour. Wash. Acad. Sci.*, vol. 5, 1915, pp. 189–212.

out then, and in later writings,[2-4] that the various ranks of coal are determined by the amount of dynamic metamorphism to which they and the enclosing rocks have been subjected; and, similarly, the distribution and quality of petroleum appear to be intimately related to the degree of deformation and accompanying pressures that the containing strata have undergone. He suggested that the quality of the coals may serve as a measure of the regional rock alteration and thus as an index of possible oil and gas accumulations. The factor he employed was the fixed carbon content of pure coal, that is, of coal on a moisture- and ash-free basis. This factor he called the "carbon ratio." It is computed by dividing the fixed carbon of the proximate analysis by the sum of the fixed carbon and the volatile matter of the same analysis. Lines joining points of equal carbon ratios are called isocarbs.

The early studies of White led to the conclusion that in areas of little disturbance, where the coals are brown lignites, the oil is of heavy quality, under 30° Bé. With increasing pressures the grade of coal rises, and concurrently the oil becomes lighter, until in regions with bituminous coal only, light oil and gas might be expected. There would be an increasing amount of gas with the higher pressures. Neither oil nor gas, however, would be expected in areas where the carbon ratios of the coals exceed 70 per cent. The dynamic pressure which would produce such a high rank of coal would have metamorphosed the sediments to a correspondingly high degree and forced out any oil which might have been present.

Fuller, applying the theory to north Texas and Oklahoma, further developed White's suggestions. His conclusions[5] regarding

[2] White, D., "Late Theories Regarding the Origin of Oil," *Bull. Geol. Soc. Amer.*, vol. 28, 1917, p. 733.

[3] "Genetic Problems Affecting Search for New Oil Regions," *Trans. A. I. M. M. E.*, vol. 65, 1921, pp. 176–198.

[4] "Progressive Regional Carbonization of Coals," *Trans. A. I. M. M. E.*, vol. 71, 1925, pp. 253–281.

[5] Fuller, M. L., "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas," ECON. GEOL., vol. 14, 1919, p. 538.

the relations between rock alteration, quality of coals, and quality of petroleum are summarized as follows:

TABLE I.

Carbon Ratios (Surface).	Prevailing Character of Sands.	Production.
Over 70.....	Hard and tight.	No oil or gas, with exceptions.
70–65.....	Tight with a few porous spots.	Usually only "shows" or small pockets. No commercial production.
65–60.....	Variable, with porous beds of limited extent.	Commercial pools are rare, but oil exceptionally high grade when found. Gas wells common, but usually isolated rather than in pools.
60–55.....	Fairly continuous and open.	Principal fields of light oils and gas.
55–50.....	Softer, less firmly consolidated, and more continuous and porous.	Principal fields of medium oils of Ohio-Indiana and Mid-continent fields.
Under 50.....	Sands usually saturated, often with fresh water, to all depths reached by wells.	Fields of heavy Coastal Plain oils, and of unconsolidated Tertiary or other formations.

Both White and Fuller draw attention to the apparent failure of the theory in faulted regions. They mention numerous cases where, near thrust faults, the coals have a lower carbon ratio than at some distance away, although the fault zone may be nearer the source of pressure and presumably subjected to greater stresses. But [6] "the areas of folding and faulting are areas in which the horizontal compressive stresses have been partially compensated and relieved by convolution and overlapping of the beds." That is, such a region may actually have undergone less stress than adjacent areas where the pressures have been resisted without much folding or faulting. Fuller [7] also notes that carbon ratios on anticlines are higher than those in synclines. The writer infers from these statements that faults and folds would be indicated on an isocarb map by irregularities in the trend of the lines; or, in other words, irregularities in isocarb lines indicate structural changes.

[6] White, D., *Trans. A. I. M. M. E.*, vol. 71, 1925, p. 264.

[7] Fuller, M. L., "Carbon Ratios in Carboniferous Coals of Oklahoma and their Relation to Petroleum," ECON. GEOL., vol. 15, 1920, p. 229.

Following the work of White and Fuller the carbon ratio theory has been applied to several fields in the United States—Alabama, Virginia, West Virginia, Kentucky, Pennsylvania, Illinois, Texas, and Oklahoma. Most of the investigators [8-16] have accepted the truth of the relationships pointed out by the earlier writers—in general principle and even as far as closely agreeing with the carbon ratio numbers which distinquish the various degrees of metamorphism and ranks of oil or gas.

Russell, who favors the theory in several articles, finds that "the fixed carbon ratios of the coals in Eastern Ohio do not afford a satisfactory index to the alteration of the Clinton sand, for the progressive increase in fixed carbon content towards the south-east is more or less masked by the considerable differences between the fixed carbon content of different beds, due apparently to original chemical difference, and by the fact that coals of higher horizons are exposed to the southeast. . . . However, in spite of the various complications enumerated, a general increase in fixed carbon content of the coals towards the south-east may be detected, and up to the present time no oil and gas production has been found in the Clinton where the fixed carbon content

[8] Semnes, D. R., "Oil Possibilities in Northern Albama," *Trans. A. I. M. M. E.*, vol. 65, 1921, pp. 140–150.

[9] Reger, D. B., "Carbon Ratios of Coals in West Virginia Oil Fields," *Trans. A. I. M. M. E.*, vol. 65, 1921, pp. 522–527.

[10] Ashley, G. H., and Robinson, J. F., "Oil and Gas Fields of Pennsylvania," Penn. Geol. Surv., 1922, 1.

[11] Eby, J. B., "The Possibilities of Oil and Gas in Southwest Virginia as Inferred from Isocarbs," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 7, 1923, pp. 421–426.

[12] Russell, Wm. L., "Relation between Isocarbs and Oil and Gas Production in Kentucky," Econ. Geol., vol. 20, 1925, pp. 249–260.

[13] Russell, Wm. L., "Porosity and Crushing Strength as Indices of Regional Alteration," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 10, 1926, pp. 939–952.

[14] Russell, Wm. L., "The Proofs of the Carbon Ratio Theory," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 11, 1927, pp. 977–990.

[15] Moulton, G. F., "Carbon Ratios and Petroleum in Illinois," Ill. State Geol. Surv., Report of Investigations No. 4, 1925.

[16] Fiske, L. E., "The Relation of Structure to Production in Five Oil and Gas Fields of the Kentucky Eastern Coal Field," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 11, 1927, pp. 477–492.

of the coals (on a moisture- and ash-free basis) is over 57.5 per cent," [17]

In the investigations already mentioned the carbon ratios employed are those of Carboniferous coals. Lilley [18] states, "Though no detailed study has been made, I have found that the limits proposed for Pennsylvanian oils and coals hold for the Cretaceous also." Hume has accepted the theory and he has applied it to the Cretaceous coal fields of western Canada. He believes [19] "that the carbon ratios of the Cretaceous coals do seem to be an index of the degree of metamorphism, and consequently the limits set by the carbon ratios permit of predicting where, other conditions favoring, oil may occur." His article deals with the area covered in this discussion and a more complete account of it will be given later in the paper.

Among the opponents of the theory who have published their views are Jones,[20] McCoy,[21] Tarr,[22] and Dorsey.[23] They believe that original differences in material and depositional agencies are the major factors causing different qualities of oil. The oil accumulations are related to ancient shore-lines—bituminous-rich sediments accumulated off-shore, while the coast was probably bordered by a belt of swamps. After burial the marine deposits would generate oil, and the carbonaceous swamp deposits would generate gas, while farther inland, where swamps were scarce, neither oil nor gas would be formed in quantity. The structural

[17] Russell, Wm. L., "Oil and Gas Accumulations in the Clinton Sand of Ohio," ECON. GEOL., vol. 21, 1926, p. 543.

[18] Lilley, E. R., "Coal as an Aid to Oil Exploration," *Eng. and Min. Jour.*, June 21, 1924, pp. 1009–12.

[19] Hume, G. S., "Carbon Ratios of Coal as an Index of Oil and Gas Prospects in Western Canada," *Bull. Canadian Inst. Min. and Met.*, March, 1927, p. 328.

[20] Jones, Wm. F., "The Relations of Oil to Carbon Ratios," ECON. GEOL., vol. 15, 1920, pp. 81–87.

[21] McCoy, A. W., "A short Sketch of the Palæogeography and Historical Geology of the Mid-continent Oil District and its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 5, 1921, pp. 541–584.

[22] Tarr, R. S., "Oil May Exist in Southeastern Oklahoma," *Oil and Gas Jour.*, vol. 24, 1925, p. 51.

[23] Dorsey, G. E., "The Present Status of the Carbon Ratio Theory," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 11, pp. 455–466.

axes of later regional uplifts follow roughly parallel to these old shore lines. Isocarbs, if they indicate metamorphism, would be parallel to the axes of folding and, therefore, parallel to the zones of deposition and to the old shore-lines. Through the coincidence of these factors carbon ratios may sometimes appear to be an index to oil and gas accumulations. The carbon ratio theory does not explain the origin of various ranks of oil; regional metamorphism is not the cause as postulated in the theory. The formation of different oils and gas can be explained, according to these authors, by the conditions of original deposition.

Tarr also points out,[24] "In its economic application the carbon ratio theory has discarded all possibilities of oil being found in the folded regions of southeastern Oklahoma. As a matter of fact, it has actually been found in several places well within the discarded zone."

These opponents of the carbon ratio theory base their opposition on the explanation of the origin of petroleum and gas. The present writer does not intend to deal with that phase of the problem, but will test the validity of the theory in western Canada from the view-point of coal alteration itself. He will point out that in this region the carbon ratios do not always indicate the rank of the coal, nor do they necessarily indicate the degree of dynamic metamorphism which the rocks have undergone, and consequently they are not an index of oil and gas accumulations, if such accumulations be due to dynamic pressure.

CARBON RATIOS IN WESTERN CANADA.

The following discussion will deal chiefly with the province of Alberta with which the writer is more familiar, but to make the discussion more comprehensive brief mention will also be made of conditions in the neighboring province of Saskatchewan.

General Geology.

The Rocky Mountains extend along the western side of Alberta, occupying a belt within its border varying from ten to fifty

[24] Tarr, R. S., Discussion of Dorsey's paper, *op. cit.*, p. 265.

miles wide. They consist of a series of great fault blocks thrust over each other. The rocks are from lower Paleozoic to upper Cretaceous in age, the latter occupying valleys between the easternmost limestone ranges. The altitude varies from 7,000 to over 11,000 feet above sea level.

The front range of the mountains, usually a Paleozoic fault block, is thrust eastwards over the Mesozoic strata of the foothills. These foothills, 25 to 50 miles wide, consist of a series of parallel ridges composed chiefly of Cretaceous rocks. The strata, especially close to the mountains, are much disturbed—folded and faulted. In general the structures decrease in number and intensity towards the east and the dips are gentler; likewise the formations become younger and the altitudes lower—from 7,000 to 3,000 feet above sea level.

In front of the foothills the strata, as far as the eye can observe, rapidly assume a horizontal attitude and this condition is retained in general throughout the remainder of Alberta, Saskatchewan and Manitoba. East of the foothills is a broad shallow trough, commonly called the "Alberta syncline," which is over a hundred miles in width in its central part. Early Tertiary strata occupy the basin, while Upper Cretaceous formations are exposed along the western and eastern edges. The western rim, constituting the edge of the foothills, has observable structures, while along the eastern border there is only a general westerly dip of seldom more than a few feet to the mile. Farther east, flat-lying Upper Cretaceous and Tertiary strata cover the greater part of Saskatchewan. The waning influence of the mountain-building stresses is clearly evident. East from the disturbed belt of the foothills the sediments are as a rule less consolidated and this feature becomes more pronounced the farther away the rocks are from the major uplift. Physiographically the region constitutes the Interior Plains—a rolling country with broad undulations and elevations decreasing eastwards.

Age, Distribution and Quality of Coal.

During Carboniferous time marine conditions prevailed in western America and consequently there are no coals of that age in the region. The coal seams of Alberta, with the exception of a few minor occurrences in the Tertiary, are all of Cretaceous age. There are three main horizons separated by several hundred feet of strata. These are the Kootenay or Lower Cretaceous, the Belly River or Saunders, and the Edmonton. The latter two are Upper Cretaceous in age. The stratigraphic relations of these formations are shown in Table II.

TABLE II.

THE CRETACEOUS OF ALBERTA.

Period.	Group.	Formation.
Upper Cretaceous	Montana	Edmonton (St. Mary's in the south). Bearpaw. Belly River (Saunders in the west-center).
	Colorado	Marine shales with some sandstone members; formational names vary with locality.
	Dakota	Dakota.
Lower Cretaceous	Kootenay	Kootenay.

The Kootenay formation occurs in long belts within the first few ranges and along the eastern front of the mountains. The coal seams of this horizon are generally much folded and faulted, with dips ranging from 0° to 90° and they may even be overturned. The second coal horizon, the Belly River formation, is found along the borders of the broad synclinal trough—that is, in the foothills in a complicated series of folds, and along the south and east as almost flat-lying beds. The Edmonton formation has a somewhat similar distribution, occurring along the outer portion of the foothills, being buried under the younger sediments in the trough, and then reappearing as horizontal beds to the east of the broad syncline. Tertiary coals are not common in Alberta, but they occur over large areas to the east in southern Saskatchewan.

The quality of the coals appears to be largely dependent on their relative position with respect to the mountain uplift. The coals become lower in rank from west to east. The Kootenay coals in the mountains are high-grade bituminous, and as a rule they are good to fair coking types. In a few regions of intense pressure,semi-anthracites are found. The Belly River and Edmonton coals vary from low-moisture sub-bituminous in the foothills to higher moisture black lignites farther east, and to brown lignites still farther from the mountains. The lowest rank of coal is found in the Tertiary of southern Saskatchewan. The latest classification[25] for Alberta coals is given in Table III. This classification shows very clearly the quality of the various coals and it is especially satisfactory in so far as districts containing similar coals are grouped together. Most classifications of previous investigators do not seem to apply to Alberta coals.

That part of the carbon ratio theory which postulates that coals increase in rank with greater dynamic metamorphism appears to be well borne out in western Canada. A study of the classification of the coals (Table III.) and the map (Fig. 1), which indicates the areas mentioned in the classification, will show clearly the decrease in quality of coal as the effect of the mountain-building stresses dies out to the east. But, in measuring the quality of the coal several factors must be considered. The amount of fixed carbon alone, for instance, will not differentiate one coal from another. In Alberta there are coals occurring out in the plains at a considerable distance from the mountains which have as great a, and even a greater, fixed carbon content than the coals in the foothills, yet they are distinctly of inferior rank and have been subjected to less dynamic pressure.

Carbon Ratios in Alberta.

A few years ago the writer attempted to apply the data obtained by White, Fuller and others to the coal fields of Alberta. He concluded that the theory was not applicable, even with modi-

[25] Stansfield, Edgar, "A Chemical Survey of Alberta Coals," *Bull. Canadian Inst. Min. and Met.*, April, 1925.

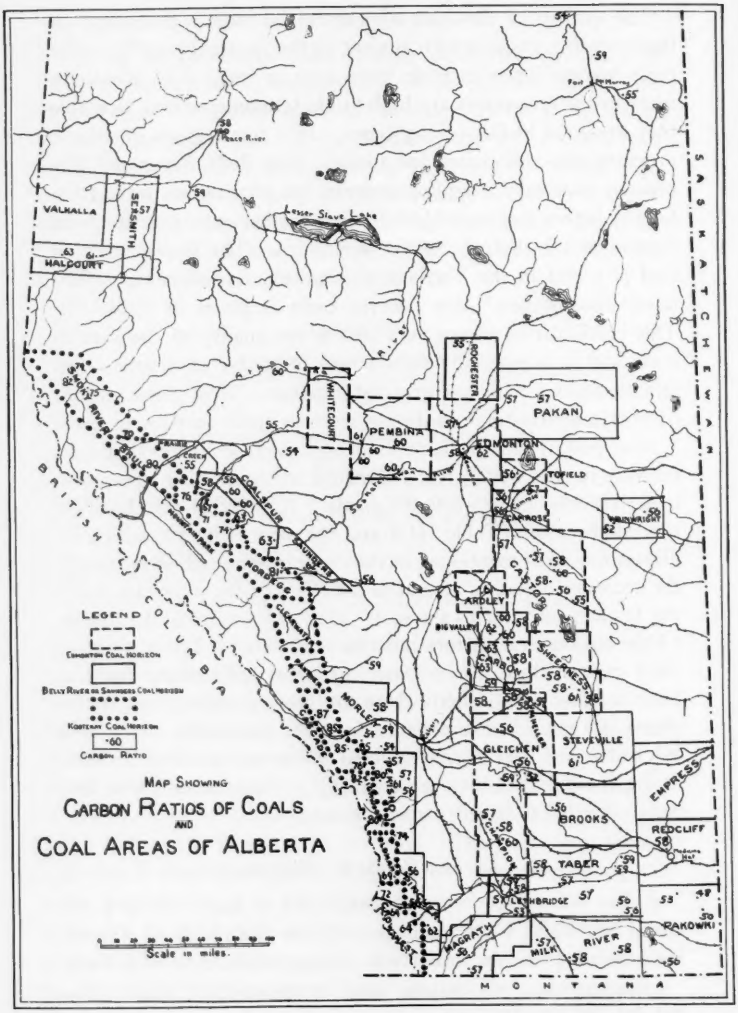

FIG. 1. Map showing carbon ratios of coals. Coal areas based on geological formations. Modified from map by J. A. Allan (Sci. and Ind. Research Council of Alberta, 1924). Carbon ratios calculated from various analyses, and plotted by I. W. Jones, 1928.

fications, to the coals in this province. Hume,[26] however, as already mentioned, believes the theory is applicable in Alberta. One would conclude from his paper that enough oil fields have not yet been opened up to permit establishing relations between carbon ratios and the character of oil which a promising area may produce. In some fields, Wainwright and Peace River for example, the carbon ratios are between 55 and 60, and light oils might be aticipated; whereas heavy oils have been found. This, Hume explains, may be due either to some original character of the oils or to their high sulphur content, it being known that sulphur tends to lower the grade of oil. He states, however, that relations between the coal and the already known occurrences of oil and gas in the province show that the "carbon ratios of the Cretaceous coals do seem to be an index of the degree of metamorphism, and consequently the limits set by the carbon ratios permit of predicting where, other conditions favoring, oil may occur (p. 328)." He has tabulated the carbon ratios for several coal areas and, employing the limits set in Fuller's table, he indicates the possibilities of finding oil and gas accumulations in each of these areas. His results may be summarized as follows:

I. Areas where carbon ratios are favorable for oil and gas accumulations—Coalspur, Magrath, Lethbridge, Pakowki, Taber, Brooks, Wainwright, Pakan, Pekisko (eastern part), Morley, Edmonton, Canmore, Castor, Tofield, Peace River.

II. Areas where the ratios are rather high and favorable for gas only—Milk River, Redcliff.

III. Areas where the ratios are so high that it is doubtful whether even gas may be found—Halcourt, Saunders, Sheerness, Drumheller.

IV. Areas where the ratios are so high that they indicate metamorphism prohibitive for oil and gas—Pincher, Pekisko (western part), Pembina, Ardley, Big Valley, Carbon.

[26] Hume, G. S., "Carbon Ratios as an Index of Oil and Gas Prospects in Western Canada," *Bull. Can. Inst. Min. and Met.*, March, 1927.

The writer does not agree with Hume's statements, for they do not appear to describe the actual conditions. Several areas that have been eliminated owing to high carbon ratios are in less metamorphosed regions than other areas where the carbon ratios are lower and where conditions have been designated as favorable for oil accumulations.

There are over three hundred mines, large and small, operating in the province. Analyses from all of these are not available, but the writer has been able to tabulate analyses from almost two hundred localities, representing nearly all the districts in which coal is known to occur. The number is not as large as may be desired, yet on the whole a fairly complete set is available—more complete than that from most other areas to which the carbon ratio theory has been applied. For some of these areas there have been numerous coal analyses from which to draw conclusions, but the number of localities which such analyses represent in some cases has not been extensive. Fuller's results in Texas [27] were based on ten localities and those in Oklahoma [28] on thirty-three, yet many later workers have applied his conclusions to their particular problems.

The writer has calculated the carbon ratios for Alberta coals from analyses published in various reports of the Research Council of Alberta, the Federal Mines Branch, and the Geological Survey of Canada. The majority were obtained from two reports,[29] both published under the supervision of the same author. Where these two publications deal with coals from the same locality the analyses are in close agreement, and it is believed that practically no error is introduced by employing the two sets. One set often serves as a check on the other if any puzzling cases arise.

All the analyses cannot be listed in this paper, as excessive

[27] Fuller, Myron L., *op. cit.*, 1919, p. 539.

[28] Fuller, Myron L., *op. cit.*, 1920, p. 230.

[29] Stansfield, Edgar, and others, "Analyses of Alberta Coal," Report No. 14, Sci. and Ind. Research Council of Alberta, 1925.

Stansfield, Edgar, and Nicolls, J. H. H., "Analyses of Canadian Fuels, Part IV.," Bull. 25, Mines Branch, Ottawa, 1918.

space would be required. Most of the calculated carbon ratios, however, have been plotted on Fig. 1. The points of equal percentage have not been joined for fear that erroneous conclusions would be drawn from the resulting isocarbs. These isocarbs would make a most attractive map and would show many interesting irregularities that would indicate, if Fuller's conclusions were applicable, numerous structural changes. Such an inference would not be permissible, as will later be shown.

It will be observed from a study of the map that the carbon ratios for the Kootenay coals in the western part of the province range from 64 to 89 per cent. They occur in a region so intensely broken that oil, if ever present, would probably have disappeared along the many avenues offered for escape.

In the foothills the principal coal fields are in the Belly River formation. The carbon ratios in this belt range from 55 to 63 per cent. Coals of the same age extending across the southern part of the province have from 53 to 62 per cent. carbon ratios, with the majority close to 60. In the Belly River coals of the Wainwright and Pakan areas, farther north and east, the ratios are from 52 to 58 per cent., with 56 being the most typical percentage.

Coals of the Edmonton formation in the foothills have carbon ratios ranging from 55 to 60. In the east central belt from Pembina and Edmonton through Drumheller, where the coals of this series are principally mined, the ratios vary from 54 to 63 per cent.

Considering the region very broadly, it is true that the highest carbon ratios are found in the Kootenay coals of the mountains. But, on examining that whole area east of the mountains, a veritable jumble of carbon ratios is perceived. There seems to be no regularity of arrangement—areas at some distance from the mountains (*e.g.*, Pembina, Ardley, etc.) have carbon ratios equal to and even greater than the carbon ratios of older coals in the foothills which are much closer to the source of dynamic influences and have undergone much greater stresses (*e.g.*, Pekisko, Saunders, Coalspur, etc.).

The Coalspur area has carbon ratios ranging from 56 to 60 per cent.; small quantities of gas but no oil have been found here. The Saunders area has ratios of 59 to 61; Morley, 54 to 58; Pekisko (east) 56 to 57, and Pincher 56 to 60. The famous Turner Valley field producing light oils (up to 72° Bé.) and much gas is in the Pekisko area.

If the carbon ratio theory be correct, certain conclusions could be drawn on the basis of relationships existing at Turner Valley and other oil fields. One would conclude that areas such as Pembina (60 to 62 per cent. carbon ratio), Ardley (60 to 61), Big Valley (59 to 62), and Carbon (58 to 63) have been subjected to so much dynamic metamorphism that the chances of finding petroleum or gas would be negative. Such areas as Sheerness and Drumheller are so close to the border line, with some ratios over 60, that the possibilities would be doubtful. Hume, as previously mentioned, did draw these conclusions but, as will be shown, a relationship between carbon ratios and dynamic metamorphism does not exist in the areas under discussion.

Evidence of the Sediments.—If the carbon ratios were a true index of metamorphism, it would follow that the sediments in the plains of Alberta are more metamorphosed than those farther west in the foothills. Such is not the case. The sediments in the Drumheller-Edmonton region are of Edmonton age and the beds are practically flat-lying—dips as much as 25 feet to the mile are rare, and even these may be due to settling during compaction. The rocks are composed of clays, soft shales, bentonite and soft, porous, sandstones. In the foothills, as at Coalspur, Turner Valley, and elsewhere, the beds are much more disturbed —faulted and twisted into sharp folds—with the shales and sandstones relatively hard and indurated. In addition to the writer's own observations, similar conclusions are to be found in the writings of Parks [30] and Dowling.[31]

[30] Parks, W. A., "Report on the Building and Ornamental Stones of Canada." vol. IV., No. 388, Mines Branch, Ottawa, 1916, p. 29.

[31] Dowling, D. B., "Structural Geology of the Alberta Oil Fields," *Trans. Can. Inst. Min. and Met.*, 1915, p. 187.

TABLE III.

SUGGESTED CLASSIFICATION FOR ALBERTA COALS BASED ON CALORIFIC VALUE AND VOLATILE MATTER OF MOIST COAL AS MINED (WITH ADJUSTED ASH).

	Short Flame	Long Flame	Sub-bituminous.	Black Lignite.	Brown Lignite.

TABLE III.

SUGGESTED CLASSIFICATION FOR ALBERTA COALS BASED ON CALORIFIC VALUE AND VOLATILE MATTER OF MOIST COAL AS MINED (WITH ADJUSTED ASH).

Title of Class.	Short Flame Bituminous.	Long Flame Bituminous.	Sub-bituminous.	Black Lignite.	Brown Lignite.
Definition of Class:					
Calorific value	Above 12,700	Above 12,700	10,700–12,700	8,200–10,700	Below 8,200
Volatile matter	Below 20%	Above 20%			
Areas by Classes:					
Kootenay horizon	Brule (80) Mountain Pk. (76–67) Nordegg (81–85) Cascade (82–89)	Mountain Pk. Crowsnest (64–72)			
Belly River horizon			Halcourt (58–63) Coalspur (56–63) Saunders (60–62) Pekisko (57–61) Pincher (56–62) Magrath (56–59) Lethbridge (54–59)	Milk R. (57–60) Pakowki (56–53) Taber (55–60) Redcliff (58) Brooks (56–57)	Pakowki Sexsmith (57)
Pincher					
Edmonton horizon				Pembina (59–62) Edmonton (57–62) Camrose (57–56) Castor (60–55) Ardley (60–61) Big Valley (58–62) Carbon (58–63) Drumheller (57–60) Gleichen (55–59) Champion (55–61)	Tofield (56–57) Camrose Castor Sheerness (58–61)
Observed Range of Analyses:					
Moisture, per cent	1.5 to 3.4	1.6 to 4.5	6.9 to 14.2	12.1 to 26.4	26.6 to 37.5
Volatile matter, per cent	14.1 to 19.6	23.5 to 30.0	30.4 to 35.9	26.9 to 34.1	26.8 to 29.4
Cal. Val., B.T.U. per lb.	13,900 to 13,540	13,590 to 12,980	12,440 to 10,740	10,650 to 8,290	8,150 to 6,460
Moisture in air-dried coal, per cent	0.7 to 1.0	0.7 to 1.3	2.5 to 8.3	10.5 to 19.0	13.4 to 21.7

Classification by Stansfield ("A Chemical Study of Alberta Coals"—Bull. C. I. M. M., April 1925).
Numbers after areas = carbon ratios, calculated by I. W. Jones and not a part of the classification.

All geologists familiar with the area, it is believed, will agree that the sediments in the Edmonton-Drumheller region are less indurated and less compacted than those of the disturbed belt in the foothills. Yet the carbon ratios of the coals in the former are in general higher, showing that they cannot be used as an index of dynamic metamorphism.

Evidence of the Coals.—One needs only to examine the coals themselves to realize the difference in metamorphism between these two regions. The writer believes that pressures are important in determining the rank of a coal; but this rank is measured by numerous factors—the heating value, moisture content, ash content, and the physical properties of the coal are as important, at least, as the carbon content. The coals of the foothills are distinctly of higher rank than those to the east in the plains—this is well shown in Stansfield's classification (Table III.)—yet the eastern coals often have the higher carbon ratios. The notable difference in the coals is apparently in their moisture content and this factor probably accounts in a large measure for the differences in quality between such coals, for example, as are mined at Coalspur and Ardley. The coals nearer the mountains have undergone greater pressure metamorphism than those to the east and the moisture has been largely eliminated by this pressure.

Table IV. gives typical proximate analyses[32] of coals from the two regions and clearly shows the comparison.

The foothill coals in this table are of Belly River or Saunders age, older than those in the plains region which are in the Edmonton formation. The former also possess better physical properties—they are harder, have greater crushing strength and can withstand weathering for quite a long period. The coals in the plains, due chiefly to their high moisture, disintegrate rapidly on exposure to air. These are only a few typical cases; several others could be given with figures proving more strongly the contention that, although the foothill coals are older, of higher rank, and more metamorphosed by pressure, they have lower carbon

[32] Proximate analyses from Stansfield—"Analyses of Alberta Coal" (1925); carbon ratios calculated by the writer.

ratios than several of the coals farther east which are distinctly of inferior quality.

TABLE IV.

ANALYSES OF SOME ALBERTA COALS.

Location.	Proximate Analyses of Coals as Mined.					Carbon Ratio.
	Moisture.	Ash.	Vol. Mat.	F.C.	B.T.Us.	
Foothills						
Coalspur	9.8	10.2	35.4	44.6	10,720	55.8
Saunders	10.5	6.3	33.5	49.7	11,420	59.7
Pekisko	7.7	9.5	33.9	46.9	11,980	56.7
Pincher	6.9	16.5	33.6	43.0	11,190	56.1
Plains						
Pembina	19.0	10.8	27.4	42.8	8,960	61.0
Ardley	20.0	9.0	28.4	42.6	9,010	59.9
Carbon	17.5	9.7	28.0	44.8	9,500	61.6
Drumheller:						
No. 7 seam	18.6	8.3	29.8	43.3	9,430	59.3
No. 5 seam	19.6	8.1	29.5	42.8	9,220	59.2
No. 2 seam	19.6	6.1	30.5	43.8	9,610	59.0
No. 1 seam	18.6	6.0	31.8	43.6	9,830	57.8

(*The seams at Drumheller are numbered from No. 1 stratigraphically upwards.*)

Other interesting comparisons can be made. For example, Table V. gives analyses [33] of several coals of the same age (Belly River) from a zone extending across the southern part of the province. It is observed that the coals improve in quality from Redcliff, well out in the prairies, through Taber and Lethbridge to Pincher, 150 miles farther west in the foothills, close to the mountains (also see Table III.); yet the carbon ratios in general decrease.

Moisture and Calorific-Value curves.—If lines are drawn through areas of equal moisture, they are found to be roughly parallel to the mountains, and a progressive increase in moisture is observed from west to east (see Fig. 2). Curves of equal calorific values show a similar relation. Such charts show clearly the true nature of the coals and the general effect of mountain-building pressures in this region. The writer doubts, however,

[33] Proximate analyses from Stansfield, *op. cit.*, 1925. Carbon ratios calculated by the writer.

TABLE V.

ANALYSES OF SOME BELLY RIVER COALS.

Location.	Proximate Analyses.					Carbon Ratio.
	Moist.	Ash.	Vol. Mat.	F.C.	B.T.Us.	
Redcliff	26.2	7.4	27.6	38.8	8,320	58.5
Taber	15.0	10.6	31.9	42.5	9,940	57.2
Lethbridge	10.2	9.3	35.8	44.7	10,980	55.6*
Pincher	6.9	16.5	33.6	43.0	11,190	56.1

* Some analyses of Lethbridge coal give carbon ratios ranging from 56 to 58 per cent.

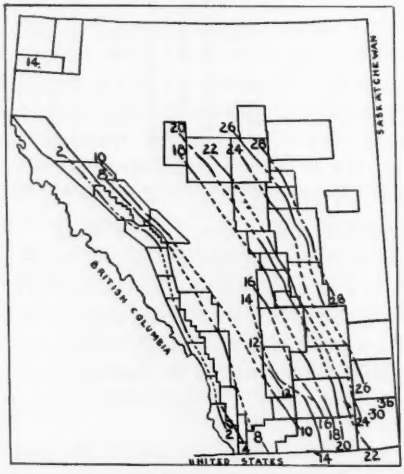

FIG. 2. Chart showing moisture in Alberta coal as mined. Taken from chart by Stansfield, " Analysis of Alberta Coals," Rept. 14, Sci. and Ind. Res. Council of Alberta, p. 14, 1925.

whether such data can be obtained with sufficient degree of fineness to indicate slight changes in metamorphism, and consequently they probably cannot be commercially applied as an index to oil and gas accumulations.

Evidence of Saskatchewan Lignites.—Further evidence that carbon ratios are deceiving is given by the Souris coal field in southeastern Saskatchewan, over 450 miles east of the mountains. The coals here are lignites distinctly inferior to those of eastern Alberta. They are of Tertiary age enclosed in soft, porous, poorly consolidated, flat-lying sediments. The coal varies considerably in quality even within the same mine. Of twelve analyses,[34] seven give a carbon ratio of 55 and 56 per cent. An average analysis[35] for the field gives: Moisture, 33 per cent.; Ash, 7; Volatile Matter, 27; Fixed Carbon, 33; B.T.U.'s per pound, 7,400. The carbon ratio calculated from this is 55 per cent. This area was little affected by the mountain-building stresses, as is shown by the higher moisture content of the coal and the physical character of the sediments, yet the carbon ratios are as high as several of those in eastern Alberta, 300 miles closer to the mountains. Some calculations (56.4) even give as high a ratio as is obtained from foothill coals which have quite obviously undergone more dynamic metamorphism. Again carbon ratios fail to indicate the rank of coal and the degree of regional metamorphism.

It may be noted, in passing that Alberta and Saskatchewan have vast areas of Cretaceous and Tertiary low grade sub-bituminous coal and lignite with carbon ratios varying from 55 to 60 per cent. Large areas of Carboniferous bituminous coals in the Appalachians, Oklahoma, Texas, and other parts of America have ratios only in that range. If carbon ratios be a criterion for measuring dynamic metamorphism, are we to conclude that these eastern Alberta and Saskatchewan coals have been as much metamorphosed as the Pennsylvania bituminous coals, and consequently are of equal rank?

It is quite evident that the carbon ratios of western Canadian coals do not indicate the ranks of coal. Coals of widely different character have equal carbon ratios, and even lower grades of coal often have higher ratios than those of much better quality. Nor

[34] Stansfield, Edgar, and Nicolls, J. H. H., "Analyses of Canadian Fuels," Part III, Bull. 24, Mines Branch, Ottawa, 1918.

[35] Galloway, J., "Lignites of Saskatchewan," *Coal Age*, Sept., 1927, p. 152.

are the carbon ratios an index of rock metamorphism, as shown by the sediments themselves. Poorly consolidated, undeformed beds enclose coals higher in carbon ratio than those in more compact, indurated and disturbed strata.

Relation to Depth.—Some Alberta coals are at variance also with some other well-known theories. Their disagreement, however, is perhaps not as pronounced or as important as in the case of the carbon ratio theory, and only passing mention is made of it here. It has been generally accepted that the fixed carbon percentages in coals increase with depth (the Law of Hilt). This relation, however, does not hold in the Drumheller field. Here there are four workable seams designated stratigraphically upwards as Numbers 1, 2, 5, and 7, with intervals[36] between of 30, 37, and 97 feet respectively. As shown in Table IV., the carbon ratios *increase upwards,* being 57.8, 59.0, 59.2, and 59.3 in typical cases for seams 1, 2, 5, and 7 respectively. Hume[37] when discussing the Drumheller coals, gives similar figures but states, "In a rough way these carbon ratios show an increase with depth." Apparently he assumed that the seams were numbered downwards. Similarly, at Lovett in the Coalspur area there are three main seams in the Saunders formation—the Mynheer, the Silkstone, and the Val d'or, named in ascending order, with intervals between them of 200 and 600 feet. The carbon ratios calculated from typical analyses[38] are: Mynheer, 59.1; Silkstone, 64.4; and Val d'or, 61.2. The lowest seam has the lower carbon content. Dowling states[39] that at Canmore, in the Cascade area, "the Stewart seam, the highest one mined, appears to be more highly altered than the Cary or Sedlock seams below it." The carbon ratios[40] for these coals are respectively 89.3, 83.2, and 82.8. Also, Dowling states, "the greater alteration is found in the synclines." This last statement does not agree with

[36] Allan, J. A., 5th Ann. Report, Alberta Sci. Res. Council, p. 38, 1925.

[37] *Op. cit.,* p. 343.

[38] Stansfield and Nicolls, *op. cit.*

[39] Dowling, D. B., "Bow River Coal Basin Within the Rocky Mountains, Alberta," Can. Geol. Surv., Sum. Rep., 1923, B. p. 82.

[40] Calculated from analyses by Stansfield and Nicolls, *op. cit.*

that of Fuller who, it will be remembered, concluded that carbon ratios are higher on the anticlines. Other instances could be cited. These few are mentioned to illustrate that exceptions occur to what are commonly regarded as general rules.

POSSIBLE CAUSES OF HIGH CARBON RATIOS IN THE PLAINS.

Theoretically, if two coals identical in character be taken and one subjected to more pressure than the other, an increase in fixed carbon would be expected in the one under stress. Since this apparently has not resulted in the area under discussion, it is of interest to investigate the probable causes for the lack of relationship between the carbon ratios of the coals and the degree of dynamic metamorphism resulting from the Rocky Mountain uplift. Such possible causes may be classified as physical and chemical.

Physical Causes.

The physical factors which might be invoked to account for the relatively high carbon ratios of the coal in the plains region are the effects of faults and static pressures.

Compensation of Faults.—It might be suggested that, although the strata in the foothills are folded and faulted, they might actually not have been subjected to as much pressure as the horizontal strata to the east. The folding and breaking of the strata might have relieved the compressive stresses and resulted in less metamorphism. If this were true, lower carbon ratios would be expected in these broken zones than in the adjacent areas where the pressures have been resisted without much folding and faulting. White and Fuller have offered this reason in explaining declines in carbon ratios in faulted regions. This explanation cannot hold in Alberta and Saskatchewan, for it is clearly evident that the coals in the disturbed foothills are actually more altered, and also the enclosing rocks are more indurated and metamorphosed, than those in the plains where the carbon ratios are as high, and even higher in some instances. It may be permissible to raise the question whether the principles enunciated by White

and Fuller need necessarily be true in all cases. Is it not possible that the faulting and folding may occur owing to the exertion of excessive pressures, and that where the beds are not so disturbed, even adjacent to the broken belt, they are in that state because they have actually been subjected to weaker forces? It is possible, moreover, that fracturing of the strata would aid in the transformation of coal from low to high rank; Campbell[41] attaches considerable importance to this factor.

White in one of his most recent articles[42] deals rather fully with the compensating effects of faults and folds. He mentions the Pine Mountain fault of eastern Kentucky as illustrating the effects of faults in relieving stresses and how lower carbon ratios are found with greater magnitude of fracture. He reproduces an isocarb map by Eby[43] showing that the carbon ratio is 67.5 per cent. at the northeast end of the fault. He states: "As this fault develops in magnitude toward the southwest the carbonization rapidly declines to less than 62.5 per cent., and even below 60 per cent. before the fault dies out at the intersection of the Elk Valley fault in northern Tennessee, beyond which point the carbonization again advances to 70 per cent." (p. 267). A later map has been published by Fiske,[44] dealing in particular with eastern Kentucky. He is in full agreement with the carbon ratio theory as propounded by White and Fuller, yet his map is quite different from Eby's. Instead of the carbon ratios decreasing southwestward from 67.5 to under 60, Fiske shows the 65-per cent. isocarb winding back and forth across the Pine Mountain fault-line for its entire length. If this later work be correct, then the Pine Mountain fault apparently does not illustrate the compensating effects of overthrusts.

Weight of Overlying Sediments.—Another explanation of the

[41] Campbell, Marius R., "Hypothesis to Account for the Transformation of Vegetable Matter in the Various Grades of Coal," Econ. Geol., vol. I., 1906, pp. 26–33.

[42] White, David, "Progressive Carbonization of Coals"—Trans. A. I. M. E., 1925, pp. 264–269.

[43] Eby, J. B., Virginia Geol. Surv. Bull., 24, 1923, Plate 37.

[44] Fiske, L. E., *op. cit.*, 1927, p. 479.

apparently high carbon ratios in the flat-lying seams of the plains area suggests itself but, in the light of other facts, it is not tenable. It is that overlying strata, which by now have been mostly eroded away, could have exerted static pressure and have metamorphosed the coal. It is not known how thick the Tertiary deposits might formerly have been, but at present they occur only in patches, except in the Alberta geosyncline and in southern Saskatchewan. Even granting the thickness to have been at one time much greater than at present, metamorphism of the underlying sediments, including the coals themselves, has not taken place to as great an extent as in the foothills. The coals do not show the effects of such an assumed load. Their high moisture content (20 to 35 per cent.) compared to those of the foothills (5 to 10 per cent.) shows that they have undergone less pressure (dynamic or static). Moreover, it may be pointed out that very probably the Tertiary deposits were much thicker in the west, where the foothills are now, than in the area farther east. If static metamorphism due to superincumbent load were a factor, it should have had a greater effect in the western part of the area.

Chemical Causes.

In studying the alteration of coals the purely chemical influences must also be considered; that is, the chemical actions that may take place without the aid of physical forces such as pressure. The fixed carbon content of the coal in one locality, or seam, may differ from that in another owing to differences in the original composition of the coal-forming plants, or to different chemical influences acting on the coals subsequent to the burial of the vegetable matter. The first may be discussed under "original differences," and the second under "secondary alterations."

Original Differences.—When applying the carbon ratio theory to other areas, investigators have found it necessary to disregard analyses of certain coals. Cannel and other "fatty" coals may be as much as 20 per cent. lower in fixed carbon than humic types such as bituminous coals and there may be all gradations between

these two types. Since it is quite possible for one coal to have more fatty components than another, an appreciable difference of, say, three or four per cent. in carbon ratios could exist without this difference in composition being apparent except by a very detailed examination. Such variations, although apparently small, may be sufficient to cause the making of inaccurate predictions of the petroleum possibilities in any given area. The carbon ratio theory is seriously weakened, in the writer's opinion, by the ease with which such errors may be introduced.

Cannels are not known to occur in Alberta, and spores, although present, do not play the important rôle in coal composition that they do in the Carboniferous coals. Resins are present, however, sometimes in appreciable quantities and may take the place of spores in affecting the fixed carbon content of the coals. It cannot yet be definitely stated, however, that the differences in the carbon ratios of Alberta coals are due to original differences, although it appears as though different types of plants, or parts of plants, may have been a factor. It must be noted that the author does not suggest that *ranks* of coal are explained by original differences, but it is possible that differences in carbon content may be due to that cause.

Secondary Alteration of Coal by Ground Waters.—It is well known that in the laboratory alkaline solutions, such as weak potassium or sodium hydroxide, are effective solvents of low grade coals. Such solutions have been observed in nature where they also serve as solvents for organic matter.

Pishel [45] found in a lignite field of North Dakota that a large quantity of the hydro-carbons is carried out of the coal bed in solution during the lignitic stage. He noticed several springs emerging from the seams and only a few of them were apparently free from this soluble bituminous matter. The strata here are only very gently inclined and the rocks above the lignite beds, owing to their sandy character, act like sieves. The water percolates through the lignite very slowly and gives the solvents in the ground water opportunity to attack the soluble part of the lignite.

[45] Pishel, M. A., "Lignite in the Fort Berthold Indian Reservation, North Dakota," U. S. Geol. Surv. Bull., 471, 1912, pp. 178–180.

The water in this general region is known to carry alkalies in solution.

Similar conditions have been observed by MacLean [46] in the Souris lignite field of Saskatchewan. He has noticed pools there containing a considerable quantity of hydrocarbon. These were near lignite seams, and he believes that there can be no possible source for them other than from the lignite. There are large areas in the plains regions where the waters are "alkaline."

Near Tofield,[47] in Alberta, a well sunk for water produces a flow of deep brown-colored solution that comes from a coal seam. It is quite probable that the material in solution consists of hydrocarbons dissolved from the coal by ground waters which may be alkaline.

Such actions must have some effect on the coal and change its composition considerably. These actions may take place over wide areas and at any time subsequent to the deposition of the coal-forming material. It is possible also that different solutions would affect the coals in different ways. Lane [48] suggested that "the composition of the water in which the vegetable deposits were laid down must have had some influence on the form and rate of decomposition, even as it does on olives and pickles today." He also suggested that oxidizing surface waters may have an effect on coal.

McKenzie Taylor's Theory.—An interesting theory dealing with the action of alkaline solutions has recently been brought forward by McKenzie Taylor [49] to explain the transformation from peat to coal. In a study of the Nile delta in Egypt he found a deposit of vegetable debris at a depth of two meters below the surface. This was found to contain peat, fusain, and partially fusainised material. Briefly his explanation for this occurrence is as follows:

[46] MacLean, A., University of Toronto; personal communication.

[47] Verbal communication from J. A. Allan, Professor of Geology, University of Alberta.

[48] Lane, A. C., Discussion of Campbell's paper on transformation of coal, ECON. GEOL., vol. 1, 1906, p. 499.

[49] McKenzie, Taylor E., "Base Exchange and the Formation of Coal," *Nature*, Sept. 24, 1927, pp. 448–9.

When vegetable matter is being transformed to peat by bacteria, toxic acids are produced that would eventually destroy the bacteria, and their activity would cease, unless some agent would neutralize the toxic solutions. In the Nile delta, calcium-silts were deposited on the vegetable matter. Later sodium chloride solutions caused a base exchange with the calcium, and sodium clays were formed. The sodium clays were afterwards hydrolysed by fresh waters and the resulting sodium hydroxide neutralized the acids in the vegetable deposit. This permitted anaerobic bacterial action to continue and fusain (" mineral charcoal," " mother of coal," etc. of other authors) was able to form.

Taylor conducted experiments in the laboratory with vegetable matter and clays and verified this explanation. He extends the idea to explain the higher ranks of coal, since bituminous coals have much fusain. He found that the roofs of bituminous coal and anthracite seams in England are alkaline and mostly of sodium-clay. Lignite seams have a calcium-clay roof, base exchange having not yet taken place. He concludes, then, that the higher ranks of coal are produced through such actions as above, and that pressure and heat are not factors of the importance ascribed to them by other investigators.

Taylor's paper is a very interesting contribution, especially in so far as it points out the important rôle which alkaline solutions may play. It is possible, however, that the action of these solutions may be similar to that taking place in North Dakota and western Canada; it may not be necessary to invoke the aid of anaërobic bacteria. Moreover, Taylor has probably gone a little too far when he ascribes to this method solely the transformation of coal to its highest ranks. Pressure undoubtedly does play a very important part and the writer believes that it is essential in most cases. Pressure or heat would at least be necessary to drive off the moisture and, as the Cretaceous coals of western Canada show, the elimination of moisture appears to be an important factor in the transformation of coal from low to high rank.

The writer is conducting some laboratory experiments on the action of various solutions. These investigations have not yet been completed, but it has been observed that hydroxides, car-

bonates and bicarbonates of potassium and sodium have a strong effect on peat and lignite. Deep brown solutions are obtained from peat, and the residue is a black coal-like substance. The hydroxide solutions may not be common in nature, but the carbonate and bicarbonate solutions, which seem to have as much solvent power, are frequently found in ground waters.

That ground water solutions do have an effect on coal has, then, been proven both in the field and in the laboratory. The effect has not, as far as the writer is aware, been expressed quantitatively, and whether there is an increase or a decrease in the carbon ratios of the residual coal has yet to be determined. It is hoped that the experiments at present under way will contribute additional information regarding this subject.

CONCLUSION.

In this paper the writer has objected to the application of the carbon ratio theory to the Cretaceous coals of western Canada. These objections are based chiefly on the grounds of geological evidence. The main objection that the chemist is likely to raise is to the employment of the "fixed carbon" value of the proximate analysis. White, who originated the carbon ratio theory, recognizes the weakness of the so-called "fixed carbon." He writes as follows:[50]

> The state in which the increasing proportions of carbon actually exist in the coal is unknown, and no exact method appears to have been employed or even devised for determining its amount. We are, therefore, compelled to fall back on the results of the very convenient, though inaccurate, unsatisfactory, even rather unscientific, "proximate analysis." However, far as the proximate analysis, with its incompatibilities, may lie from the ideal of chemical truth, it nevertheless furnishes a scale indicating the amounts of conventionally accepted "fixed carbon" in the coals of middle bituminous and higher ranks, though it leaves great lack of information as to the progress of carbonization in the coals of lower ranks.
>
> In the coals below (as well as above) the middle bituminous rank the progressive evolution or carbonization of the fuel is closely indicated by the decrease of oxygen (ash and moisture-free basis) in the coals, or by the ratio of such oxygen to the total carbon. Unfortunately, the applica-

[50] White, D., "Progressive Regional Carbonization of Coals," *Trans. A. I. M. M. E.*, vol. 71, p. 256, 1925.

tion of this method requires "ultimate" analyses, which may not be at hand.

Perhaps the carbon ratio theory as originally announced and applied is not to be condemned. But objection must be made to the promiscuous application of the theory made by later authors under widely different sets of conditions. The writer maintains that the theory is not applicable to the Cretaceous coals, despite the belief of Lilley and Hume that it does hold for the coals of that age. The writer has not visited the neighboring Tertiary and Cretaceous coal fields of Dakota, Montana and other western States. However, a general perusal of reports covering parts of these areas suggests the probability that conditions prevail there similar to those in western Canada.

Western Canada, owing to its extent and the existence of a wide range of conditions, offers excellent opportunities for studying the problems of coal metamorphism. Consequently the conclusions reached in this paper cannot be regarded as merely local exceptions to a general rule.

It is concluded that:

The ranks of coal in western Canada are apparently intimately related to the dynamic metamorphism to which they have been subjected. But the "carbon ratios" show no such relation. They do not indicate the ranks of coals, nor are they a criterion for measuring the dynamic metamorphism of the enclosing rocks.

Carbon ratios cannot be applied in this region as an index to oil and gas accumulations.

Variations in carbon ratios may not necessarily be due to various degrees of dynamic or static metamorphism.

It is possible that various influences may cause differences in carbon ratios; of these, there have been suggested the possibility of original chemical differences in the coals, and of secondary alteration by circulating ground waters.

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EXPERIMENTS BEARING ON BORNITE–CHALCOCITE INTERGROWTHS.[1]

G. M. SCHWARTZ.

INTRODUCTION.

In a recent paper[2] the writer reported experiments bearing on the origin of chalcopyrite-cubanite intergrowths. In continuing this line of investigation attention was naturally drawn to bornite and chalcocite intergrowths as these have received more attention than any other intergrowths of ore minerals. Moreover, Wandke's[3] experiments showed that these minerals, on heating tended to form a homogeneous material, or, in other words, a solid solution. Experiments carried out during the past two years have shown conclusively that a solid solution will form from bornite and chalcocite on proper heat treatment, and that the two mineral phases may be reprecipitated on slow cooling forming a very intimate intergrowth not unlike some of the natural ones hitherto described.

The writer is especially indebted to Mr. Francis G. Wells for assistance in the experimental work, and to Dr. W. H. Emmons, Dr. F. F. Grout, and Dr. John W. Gruner for many suggestions

PREVIOUS WORK.

Various intergrowths of bornite and chalcocite have been described and various origins assigned beginning with Laney's[4] paper on the Virgilina district published in 1911.

[1] The work on which this paper is based was aided by a grant from the research fund of the Graduate School of the University of Minnesota.

[2] Schwartz, G. M., "Intergrowths of Chalcopyrite and Cubanite," ECON. GEOL., vol. 22, pp. 44–61, 1927.

[3] Wandke, "Molecular Migration and Mineral Transformation," ECON. GEOL., vol. 21, pp. 166–171, 1926.

[4] Laney, F. B., *Proc. U. S. Nat. Mus.*, vol. 40, pp. 513–524, 1911. Ransome, F. L., U. S. Geol. Surv. Bull. 540, pp. 139–158, 1912. Graton and Murdoch, *Trans. A. I. M. E.*, vol. 45, pp. 26–93, 1913. Gilbert and Fogue, *Proc. U. S. Nat. Mus*,

It would be difficult to find a problem on which there have been more varied opinions than as to the origin of these structures, and the emphasis has varied with time from one interpretation to another. These interpretations have, however, been based mainly on microscopic examination and field occurrence.

Because so much has been written regarding these microstructures a complete summary would be too long; therefore only such data will be noted here as is necessary to an understanding of the problem on which the experimental data here reported have a bearing.

Chalcocite and bornite occur as microscopic intergrowths of quite different types. These have been classified as:

A. Graphic intergrowths.
B. Subgraphic intergrowths.
C. Lattice or grating structures.[5]
D. Ice cake[6] structure.
E. Mutual boundaries.

The so-called graphic structures are probably the most common, or at least, they have received the most attention. The graphic intergrowth of chalcocite and bornite was first described by Dr. Laney[7] who considered it to represent crystallization at the eutectic point of the solution. Later Rogers and others attributed the origin to replacement. Whitehead showed that the term eutectic could not be applied as there is an excess of both minerals as a rule. If a true eutectic is present only one constituent can be in excess.[8] More recently Locke, Hall, and

vol. 45, pp. 609–625, 1913. Rogers, A. F., *Min. and Sci. Press*, vol. 109, pp. 680–686, 1914. Segall, J., ECON GEOL., vol 10, pp. 462–470, 1915. Ray, J. C., ECON. GEOL., vol. 11, pp. 179–185, 1916. Tolman, C. F., *Trans. A. I. M. E.*, vol 54, pp. 402–435, 1916. Whitehead, W. L., ECON. GEOL., vol 11, pp. 1–13, 1916. Rogers. A. F., ECON. GEOL., vol. 11, pp. 582–593, 1916. Schneiderhöhn, "Untersuchung von Erzen," Berlin, 1922. Locke, Hall and Short, *Trans. A. I. M. E.*, vol. 70, pp. 933–963, 1924. Per Geijer, Sveriges Geologiska Undersökning, Ser. C, No. 321, 1924. Van der Venn, R. W., "Mineralography and Ore Deposition," Delft, Holland, 1925. Short and Ettlinger, *Trans. A. I. M. E.*, vol 74, pp. 174–222, 1926.

[5] Short, M. N., and Ettlinger, I. A., *op. cit.*

[6] Tolman, C. F., *op. cit.*

[7] Laney, F. B., *op. cit.*

[8] The phase rule accounts for this fact.

Short[9] state that the graphics are duplicates of alloy eutectics. This is probably true in some specimens, but certainly is not true in most of those observed by the writer or shown in many of the published photomicrographs for the reasons given by Whitehead. A comparison with the eutectic patterns in metallic alloys shown by Miss Green[10] brings out the distinction very clearly.

Still more recently Short and Ettlinger have shown certain examples of the graphic type of intergrowth. Their figures 23 and 24 show intergrowths which fulfill the requirements of a eutectic deposition of bornite and chalcocite with bornite considerably in excess.

It is evident that there is a lack of unanimity as to the significance of graphic structures. This is doubtless due to the various writers examining different material and approaching the problem with a different point of view. It seems reasonable to suppose that the structures may be formed in more than one way. The writer has pointed out a case where good graphic structures apparently originated by supergene action.[11] A good case for their origin by replacement has been made in some of the papers cited and certainly evidence indicating a contemporaneous, if not eutectic, origin is not wanting.

Subgraphic intergrowths are defined as follows:[12] "Occupying, in character, a half-way position between the mutual and graphic structure is the so-called 'subgraphic.' This has suggestions of the graphic, but lacks the complete graphic pattern." The significance of these structures is practically the same as that of the well developed graphic structure.

Lattice (or grating) structures of chalcocite and bornite are of two types, as has been noted by Locke, Hall, and Short.[13] The first type is definitely related to channels from which blades of chalcocite extend outward. This is usually considered a good criterion for supergene replacement. The second type of lattice

[9] *Op. cit.*, p. 27.

[10] Green, C. H., "Eutectic Patterns in Metallic Alloys," *Trans. A. I. M. E.* vol. 71, pp. 651–665, 1925.

[11] Schwartz, G. M., Discussion, *Trans. A. I. M. E.*, vol. 70, pp. 962–963, 1924.

[12] Locke, Hall, and Short, *op. cit.*, p. 956.

[13] *Op. cit.*, p. 23.

or grating structure is independent of visible channels and in some specimens pervades nearly all the chalcocite. The structure has been attributed to replacement and to contemporaneous deposition. Segall [14] considered it to be a replacement of chalcocite by bornite. Most others have attributed it to replacement of bornite by chalcocite. In general this structure has been considered a much more positive indication of replacement than the graphic structure, but the writer's experiments show that it probably developed by the breaking down of a solid solution, a possibility which might be inferred from Wandke's [15] experiments which showed that chalcocite and bornite form a solid solution on heating.

The so-called "ice cake" structure is considered to represent corroded remnants of bornite in chalcocite, and forms by replacement.

Other relations, such as mutual boundary between the two minerals, are common, but need not be discussed here. The graphic intergrowths and lattice structures are the important types from the point of view of this paper.

The writer has recently discovered a natural intergrowth unlike any thus far described for bornite and chalcocite. The ore is from Susie Island,[16] Lake Superior, and a polished surface shows blades of bornite arranged along the cleavage directions of chalcocite (see Fig. 3). This type should be added to the list given above.

EXPERIMENTAL METHODS.

Heat treatment: In all of the work carried on thus far natural mixtures of bornite and chalcocite comparatively free from other minerals have been utilized. More work on pure synthetic material is desirable as varying percentages of each can thus be obtained. Most of the specimens used were from Butte, Montana, but a few from Globe, Arizona, and Engels, California, were also utilized. The original specimens in some cases show

[14] *Op. cit.*, p. 464.
[15] *Op. cit.*
[16] A description of these deposits is in preparation.

typical lattice and graphic intergrowths; others merely coarser mixtures of bornite and chalcocite of the mutual type. For most purposes the structure of the original is not important, since this structure is entirely destroyed when the minerals form a solid solution. The more minute the intergrowth, of course, the more easily the two dissolve. Raising the temperature somewhat, results in more rapid solution of coarser types. Relative freedom from other minerals and abundance of the material were usually the governing factors in selecting the experimental specimens.

The general method used consisted in polishing and studying small specimens of relatively pure bornite and chalcocite. It was found advisable to examine the surfaces with magnification up to about 800 diameters, using an oil immersion lens for the higher magnifications. The specimens were then inserted in pyrex tubes of about ¾ inch diameter and carefully sealed with an oxygen flame. The tubes and a thermocouple or mercury thermometer were placed in a small electric resistance tube furnace and heated to the desired temperature, controlling with suitable rheostats. For solution experiments the specimens were held at constant temperature for certain lengths of time and then quenched by dropping into cold water. Caution in quenching is necessary as minerals like enargite cause rather violent explosions and it is necessary to shield the face. Experiments designed to reprecipitate or segregate the two minerals from a solid solution require a slow lowering of temperature by varying the resistance. This phase of the work requires more constant attention. It was found that cooling at not over 10° C. per hour resulted in precipitation of the two minerals. The temperature was held nearly constant over night as the cooling involved three days in most cases.

Following the heat treatment, the specimens were repolished and examined at low and high magnifications. Selected specimens were further determined by securing X-ray diffraction patterns of the powdered minerals. In all cases, the specimens were quenched and examined to determine if a solid solution had formed before the slow cooling to allow reprecipitation of the two phases.

RESULTS OF EXPERIMENTS.

Eighteen series of experiments were made varying from a few hours to fourteen days in length. As a rule a single polished specimen was utilized, but in some cases as many as six were included in one test. The general rule was to have a large enough specimen for the solution experiment to allow it to be cut in half and one half preserved in the solid solution state and the other half reheated and cooled slowly to allow segregation of the two phases.[17] It is often desirable to contrast the specimens under the microscope rather than depending on the memory for the appearance of the solid solution. The highest temperature used was 400° C., which is far below the fusing point of the sulphides. Chalcocite, for example, melts at 1,130° C.

As a result of these experiments it was determined that a small percentage of bornite (5 to 15 per cent.) would dissolve in chalcocite at 225° if heated for 24 hours (see Fig. 4). The diffusion is not quite complete at the end of this time as the bornite areas are somewhat bluish. Various experiments were run at lower temperatures, but in no case was a homogeneous field obtained. A Butte specimen showing a very fine lattice structure was heated at 150° C. $\pm$ 10° for 8 days with little evidence of solution. The temperature was checked by both thermocouple and mercury thermometer. This does not agree with Wandke's[18] result and several runs were made at temperatures varying from 150° C. to 200° C., without success. It is possible that Wandke's method did not permit an accurate determination of the temperature of the specimens as they were not sealed as in the writer's experiments.

There is, however, some solution as low as 170° C., but complete diffusion could not be obtained. Specimens held at that temperature for many hours show a decided gray or bluish zone around the bornite areas. This zone grows wider with prolonged heating and evidently represents the diffusion of bornite into the chalcocite which then becomes grayish or bluish. In some speci-

[17] It is perhaps proper to refer to the reprecipitated compounds as phases rather than as minerals, a term reserved by definition for natural substances.

[18] Wandke, A., ECON. GEOL., vol. 21, pp. 166–171, 1923.

mens the bornite is apparently changed to a grayish or bluish color as compared with the white chalcocite. This persists at temperatures of 175° C., but an entirely homogenenous substance may be obtained by heating at considerably higher temperatures. In nature, where specimens might be held for years at 175° C., complete diffusion would doubtless take place. In general, at temperatures of 300 and 400° C. solution is much more rapidly completed than at 225° C.

The rate of cooling is an important factor in the experiments which reprecipitate the minerals from the solid solution. Too rapid cooling either does not allow the segregation of the two minerals or the intergrowth is too minute to be recognized. Recognizable textures were secured in as short a time as 37 hours but it was found desirable to use about 70 hours to secure textures coarse enough to be studied without too much difficulty although an oil immersion lens is necessary in practically all cases. The writer has used the large Leitz metallograph with an arc light for both study and photographic purposes.

Further investigation of the rate of cooling and inversion points is desirable. One attempt was made to locate a possible eutectoid point by using a large Weston potentiometer but no point of arrest was located. The microstructures strongly indicate a definite eutectoid point and future experiments should locate this exactly.

NATURE OF REPRODUCED INTERGROWTHS.

As stated above, there are several types of natural intergrowths of bornite and chalcocite. Three of the types of special significance are shown in Figs. 1, 2 and 3. Inasmuch as the natural intergrowths of these minerals are of varying types it is not surprising to find that intergrowths produced by precipitation from an artificial solid solution are variable. Although the experiments made thus far do not determine with finality the reason for the variable textures, some inferences may be made. It is probable that work with synthetic material of which the composition is exactly known will be necessary to clear up many of the points involved.

FIGS. 1–6.

FIG. 1. Bornite (dark) and chalcocite (light) as graphic intergrowth. Note excess of both constituents. Butte, × 135.

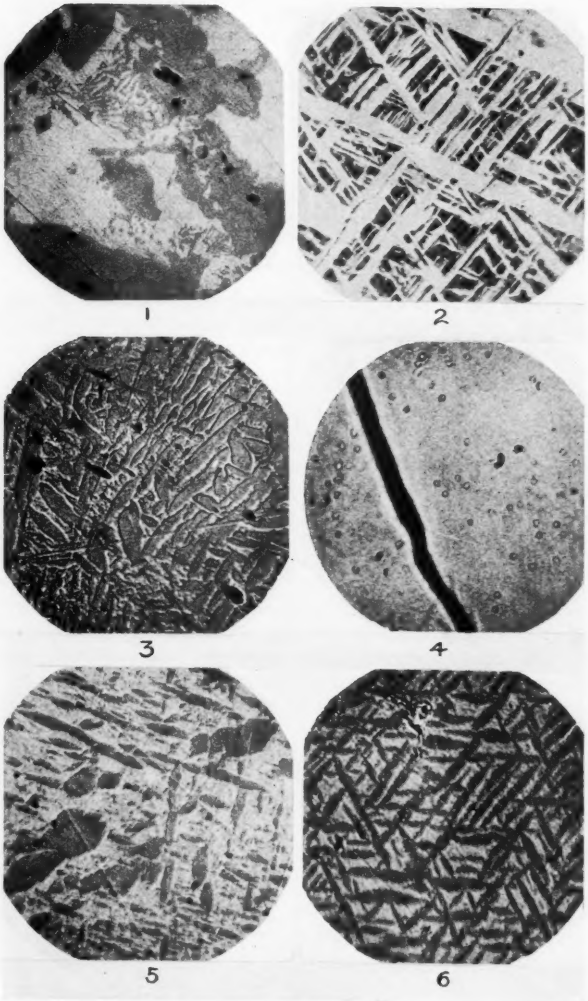
FIG. 2. Chalcocite (light) and bornite (dark) forming a triangular lattice intergrowth. Compare with Figs. 7 to 9. Butte, × 700.

FIG. 3. Bornite (dark) blades in chalcocite. Compare with Figs. 5 and 6. Susie Island, Lake Superior, Minn. × 700.

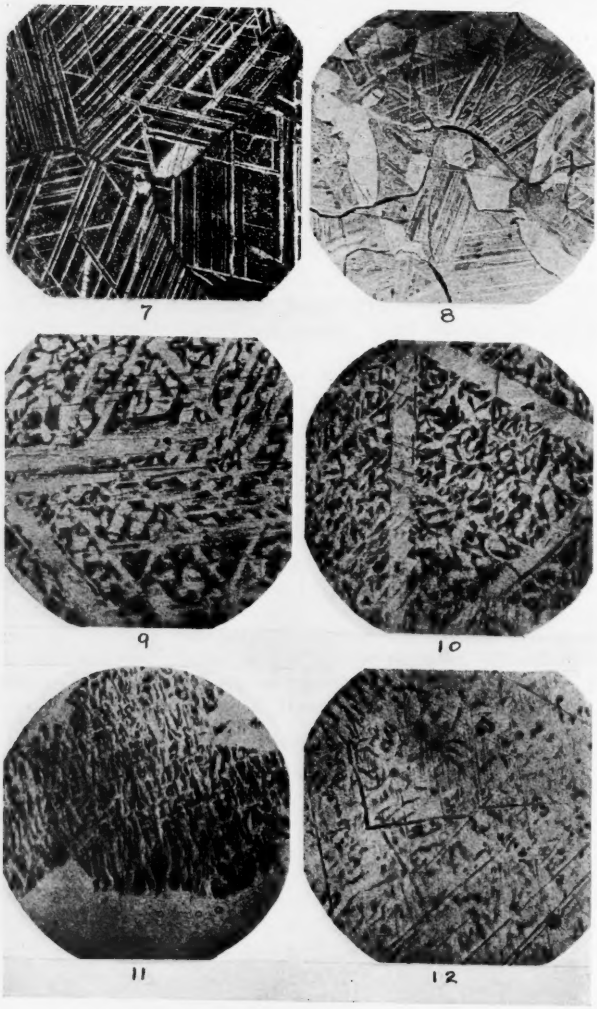
FIG. 4. Part of same specimen as Fig. 1. Contains about 85 per cent. chalcocite and 15 per cent. bornite. Heated at 225° C. for 28 hours and quenched. Shows no evidence of the two minerals; they have formed a solid solution. The dark line was an original grain boundary. × 700.

FIG. 5. Specimen from Iron Cap mine, Globe, which contained approximately 60 per cent. of bornite and 40 per cent. chalcocite. Heated at 200° C. until bornite partly dissolved, then cooled from 200° C. to 36° C. in 60 hours. Bornite blades in chalcocite. Compare with Fig. 3. × 700.

FIG. 6. Specimen from Engels, California. About equal parts of bornite and chalcocite. Heated at 350° C. for 68 hours. Quenched, reheated, and slowly cooled. The micrograph is from an area relatively high in bornite. Note arrangement of bornite in three directions. × 700.



FIGS. 1–6.



FIGS. 7–12.

FIGS. 7–12.

FIG. 7. Specimen from Butte, containing about 65 per cent. chalcocite and 35 per cent. bornite, heated to form a solid solution, then cooled from 300° C. to 60° C. in 69 hours. Etched with KCN. Chalcocite has isometric structure. × 175.

FIG. 8. Different specimen of Butte chalcocite and bornite heated to form a solid solution, then reheated and cooled from 300° C. to 50° C. in 52 hours. Chalcocite grains and triangular pattern of chalcocite and bornite. Chalcocite in excess. × 135.

FIG. 9. Same as Fig. 8 more highly magnified. Triangular pattern of chalcocite with bornite-chalcocite intergrowth enclosed. The enclosed intergrowth probably represents an eutectoid pattern. × 700.

FIG. 10. Taken from same specimen as Fig. 7. Same interpretation as Fig. 9. × 660.

FIG. 11. Part of same specimen as Fig. 1. This micrograph taken after reheating specimen of Fig. 4 to 220° C. and cooling to 80° C. in 37 hours. Bornite (dark) intergrown with chalcocite. × 660.

FIG. 12. Two colors of chalcocite (?). Formed by slow cooling of a specimen very low in bornite. × 700.

Fig. 4 shows a microphotograph of a field of a solid solution obtained by heating, at 225° C. for 48 hours and quenching, the specimen from which Fig. 1 was photographed. There is no evidence under the microscope of the existence of two minerals (phases) as in each of the other eleven figures shown. The only logical conclusion is that the bornite and chalcocite have dissolved to form a solid solution. To reproduce the two minerals it is only necessary to reheat to the same temperature and cool very slowly. The reproduced textures will bear no relation to the original texture if diffusion has been complete. The relative amounts of chalcocite and bornite present are perhaps the most important factors aside from the rate of cooling. Impurities which are always present in natural specimens may have an effect which can not be determined.

The most common reproduced texture in a series of nine slow cooling experiments is shown in Figs. 8 to 10. This texture apparently varies with the amount of chalcocite present. Fig. 8, for example, shows grains of chalcocite embedded in a triangular lattice intergrowth of bornite and chalcocite. The microscopic texture corresponds in an ideal manner with the texture produced when two minerals precipitate out of a solid solution at a given temperature and concentration (the eutectoid). The phase in excess precipitates out until the eutectoid point is reached when both phases precipitate out together forming an intimate texture. Figs. 9 and 10 represent the texture where the eutectoid composition was very closely approached. Neither phase is in excess unless the blades of the chalcocite represent excess. The triangular blades of chalcocite of Fig. 10 correspond to the natural texture shown in Fig. 2 and it is probable that natural lattices of this type form by the breaking down of a solid solution. Figs. 5 and 6 show artificial segregation textures corresponding almost exactly with the natural lattice of Fig. 3. This type of intergrowth was artificially developed in a specimen from Globe in which bornite predominated in a ratio of about 60 to 40. The bornite occurred as large areas and prolonged heating with quenching and observation at intervals failed to give a

complete solution. It was obvious, however, that some solution took place, as the borders of the bornite faded gradually into the chalcocite. The highest magnifications showed but one phase in the transition zone and the width of the zone increased with the time of heating. Prolonged heating did not result in complete solution, due either to the large size of the bornite areas, or to saturation of the chalcocite with bornite. On reheating and slowly cooling this specimen the textures of Figs. 5 and 6 developed. At low magnifications the bornite appears to fade into the chalcocite, but under high magnification this is found to be due to the decrease in the number of blades of bornite in the chalcocite. The same texture was observed in other specimens treated in a similar manner. A natural specimen duplicating the artificial texture was found in ores from Susie Island, Lake Superior (see Fig. 3).

The distinct difference between the intergrowths described above and those shown by Figs. 7 to 11 suggests that a difference in precipitation occurred depending on relative amounts of bornite and chalcocite present. Numerous experiments showed that a small amount of bornite dissolved in chalcocite and essentially disappeared, the chalcocite turning darker in color. It was not possible by any experiments carried on thus far to cause a small amount of chalcocite to disappear in bornite, but rather the chalcocite area remained recognizable, although it turned much darker and the bornite faded gradually into it. This suggests that bornite tends to dissolve in chalcocite, more easily than chalcocite in bornite.

Two specimens of bornite containing about 10 per cent. of chalcocite from Engels, California, were heated for 3 days at 325° C., quenched, then one returned and cooled from 325° C. to 50° C. in 48 hours. The original specimens showed extensive areas of bornite with a few magnetite grains. Smaller areas, apparently chalcocite, occurred in the bornite, but under the microscope these were observed to be largely a graphic intergrowth of chalcocite and bornite. After the heat treatment, examination at magnifications of 800 times showed that the areas where

bornite and chalcocite had been in contact contained a beautiful lattice intergrowth like Figs. 5 and 6. The bornite seemed to occur as laths even when it greatly predominated over chalcocite. At some distance from the original chalcocite area bornite remained pure. In the center of the larger area of chalcocite an intergrowth much like Fig. 11 was found. None of the chalcocite was free from bornite. Bornite had certainly diffused into chalcocite and chalcocite had evidently diffused into bornite. Where chalcocite predominated one type of intergrowth (Figs 7 to 10) predominated and where bornite was in excess another type of intergrowth appeared (Figs. 5 and 6).

In order to study more closely the effect of varying percentages of chalcocite and bornite another specimen from Engels, California, was selected. This showed about equal parts of bornite and chalcocite. The great part of the bornite occurred as large and rather pure masses, but the chalcocite contained many fine graphic intergrowths of bornite. This specimen was heated at 350° C. for 68 hours and quenched. The graphic intergrowths had entirely disappeared and the chalcocite and bornite faded into each other at the former contacts of large areas, without any visible mixture of two distinct minerals in the transition zone. Solution had been obviously very active, but to render such a coarse mixture entirely homogeneous would doubtless require many days if not weeks. The specimen was then returned and slowly cooled from 350° C. to room temperature. Examination at high magnifications then showed in the former bornite areas a bladed intergrowth like Figs. 5 and 6. In the center of the former chalcocite areas appeared intergrowths like those of Figs. 7 to 10 and between these areas where exactly the proper composition existed was a eutectoid structure like that within the triangle of Fig. 10. This seems to prove conclusively that the relative percentages of the minerals present determines the nature of the intergrowth.

Both of the types of intergrowths suggest a control by an isometric crystal structure. Since both bornite and chalcocite (above 91° C.) are isometric it is probable that the isomorphous

mixture of the two which exists at elevated temperatures crystallizes in the isometric system and thus the intergrowth in which either is in excess is controlled on precipitation by the isometric lattice. When the exact eutectoid composition exists the precipitation of the two phases takes place rapidly and there is little evidence of the isometric structures in the intergrowth.

Graphic structures similar to Fig. 1 were not obtained in any experiment made thus far. The nearest approach is shown by Fig. 11. This is a minute intergrowth of bornite and chalcocite in certain areas in chalcocite. It was obtained from the natural specimen represented by Fig. 1 and the solid solution shown in Fig. 4. The solid solution specimen was cut in two and one half reheated and cooled from 220° C. to 80° C. in 37 hours. Careful examination of the specimen at high magnifications shows areas which somewhat resemble Figs. 8, 9 and 10.

In specimens which contained only a small amount of bornite (probably not more than 3 per cent.), it was found that slow cooling did not necessarily result in the precipitation of bornite, but the two phases shown in Fig. 12 were obtained. The identity of these phases is not certain, but the specimens bear a close resemblance to the two varieties of chalcocite referred to as blue and white chalcocite by numerous investigators. It is probable that one of the two kinds of chalcocite (the blue) in these specimens may be a solid solution of chalcocite with a small amount of bornite. Covellite also is said to form a solid solution with chalcocite.[19]

X-RAY DATA.

A series of thirty diffraction patterns of powdered material were made by exposure to the X-rays from a molybdenum target in an attempt to correlate the microscopic evidence with the changes in the space lattices represented. Considerable difficulty was met with and only about half of the exposures were of value. Part of the difficulty seemed to be due to the extremely fine grain developed by heating and grinding. It is hoped to continue the

[19] Posnjak, Allen, and Merwin, "The sulphides of Copper," ECON. GEOL., vol. 10, pp. 492–532, 1915.

X-ray work with improved apparatus. Diffraction patterns were obtained from bornite, chalcocite, a natural mixture of chalcocite and bornite, the solid solution, and the reprecipitated intergrowths of chalcocite and bornite.

By comparison with an available pattern of chalcopyrite and with Kerr's [20] pattern for covellite it was concluded that the patterns obtained were not complicated by either chalcopyrite or covellite. The lattices of these minerals were not present in the original specimens nor developed by the heat treatment. The patterns obtained for bornite and chalcocite compared well with those shown by Kerr. The chalcocite was stated by him to have been orthorhombic.

The patterns of natural mixtures showed the chalcocite (presumably orthorhombic) lines predominant as would be expected from the composition of the samples used. The patterns obtained from powders of specimens judged from polished surfaces to be solid solutions showed a pattern similar to that of bornite with an additional heavy line which was not found either in bornite or chalcocite.

The patterns from reprecipitated specimens of the type shown in Figs. 7 to 11 resembled the pattern of the solid solution except for a definite shift in the lines. The extra line found in the case of the solid solution was even more prominent in the reprecipitated specimens.

From the available data it seems that the solid solution has a lattice similar to, but not exactly like that of bornite at normal temperatures. Inasmuch as the specimens contained a high percentage of chalcocite it is clear that chalcocite changes its lattice at the inversion point (91° C.) and it may be suspected that the lattice above 91° C. is similar to that of bornite. For some reason the chalcocite does not invert to the orthorhombic lattice on cooling within an interval of 70 hours. This fact is indicated not only by the X-ray diffraction pattern, but also by the microstructure of Figs. 5 to 11. This may be due to bornite remaining in solution in the chalcocite and preventing the inversion as has

[20] Kerr, P. F., "Determination of Ore Minerals by X-ray Diffraction Patterns," ECON. GEOL., vol. 19, pp. 1–34, 1924.

been shown to be the case with chalcocite containing covellite in solid solution.[21] It was found, as noted above, that a small amount of bornite dissolved in chalcocite by heat treatment does not always reprecipitate by slow cooling. It is highly desirable that both chalcocite and bornite be studied in detail by the X-ray methods.

CONCLUSIONS.

1. Chalcocite and bornite form a solid solution at high temperatures. Evidence of solution has been obtained at 175° C., but complete solution of fine intergrowths was obtained only at 225° C. or above.

2. The solid solution of chalcocite and bornite, except for very small percentages of bornite, will break down into chalcocite and bornite if cooled slowly. The breakdown results in crystallographic intergrowths of two types depending on the relative amounts of chalcocite and bornite.

3. The experiments suggest that the natural triangular lattice intergrowth and the intergrowth of blades of bornite in chalcocite are formed by the breakdown of a solid solution after deposition.

4. The intergrowth commonly produced with triangular blades of chalcocite suggests simultaneous precipitation at an eutectoid point.

5. A small amount of bornite will dissolve in chalcocite and on slow cooling form an intergrowth similar to the mixtures of blue and white chalcocite described in the literature.

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[21] Posjnak, E., Allen, E. T., and Merwin, H. E., *op. cit.*

A HYDROTHERMAL ORIGIN OF CORUNDUM AND ALBITITE BODIES.[1]

ESPER S. LARSEN.

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INTRODUCTION.

Rocks made up chiefly of sodic plagioclase (albitite) or of sodic plagioclase with varying amounts of corundum (plumasite) have been described in the last few years from Natal, South Africa (5),[2] Transvaal, South Africa (8); Pennsylvania and Maryland (7); North Carolina and Georgia (3, 4, and 9); Finland (10); and the Urals, Russia (6). In all the occurrences the albitite and albite-corundum rock (plumasite) cuts serpentine, peridotite,

[1] Published with permission of the Director of the United States Geological Survey.

[2] The numbers in parenthesis refer to the literature listed at the end of the paper.

pyroxenite, hornblendite, or other ultrabasic rocks and, in all, the ultrabasic rock next the albitite or plumasite is altered in a similar manner with a layer of biotite, phlogopite, or their alteration product, vermiculite, next the albitite; a layer of actinolite or anthophyllite next the biotite; and a layer of talc next the unaltered ultrabasic rock. A similar origin is attributed to all of them.

DuToit (5) in 1918 concluded that the Natal albite-corundum rock was formed from a normal granite pegmatite by reaction between the pegmatite and the ultrabasic wall rock. The silica removed from the pegmatite goes to form the talc and amphibole of the altered zone of the basic rock, as these minerals are higher in silica than the olivine or serpentine of the ultrabasic rock. This mode of origin has been accepted by the authors who have described the other occurrences of albite-corundum rock and albitite listed above, and the bodies have been called desilicated pegmatites.

It is the purpose of this paper to show that reactions between dike rocks, and in particular pegmatites, and their wall rocks on the scale required by the theory of desilicated pegmatites, are very exceptional, if any are well established; that the minerals and relations of the reaction zones are not such as would be expected from direct magmatic reaction between a pegmatite magma and an ultrabasic rock; that, when considered quantitatively, the material that must have been taken from the pegmatite is excessive, and has little similarity to that added to the ultrabasic rock of the reaction zone, and, finally, the field relations, such as a conspicuous lack of relation between the size of the dike and the width of the reaction zone, cannot be satisfactorily explained on the theory of desilicated pegmatites, but that all the facts available can be explained as due to moving solutions, probably hydrothermal solutions.

Emphasis will be placed on methods of reasoning, and in particular on: (1) the necessity of considering all the data, especially the chemical data, quantitatively; (2) on the greater probability of an explanation that fits easily into our commonly accepted explanations and our common experience as opposed to

one that is unique or unusual; (3) the fact that the danger of following an accepted explanation without careful scrutiny and especially of allowing it to prejudice our observation of the facts, or to prevent us from clear, independent thinking is great and probably never entirely avoided; (4) the importance of detailed observations in the field.

DESCRIPTIONS AND GEOLOGIC RELATIONS.

The description of the Pennsylvania albitites is in part from my own observations, as I spent nearly a week in the field studying these bodies and some time in the laboratory examining my collections. The other descriptions are taken from the literature.

Natal, South Africa.—DuToit (5) gives an excellent description of the Natal plumasite. The prevailing rocks of the region are hornblendic schists, granulite, and gneiss, originally basic igneous intrusives and probably extrusives.

> Prior, however, to their granitization the basic complex had been intruded by ultrabasic bodies—apparently sill-like in habit—now serpentinized, and these are also traversed by the ubiquitous aplitic dikes and veins (5, p. 54).

The aplites in the serpentine are seldom more than a few feet in width on the average, but they are irregular both in thickness and direction; their manner of ending, too, is frequently abrupt. They are white, compact, fine-textured rocks, devoid of quartz and carrying little orthoclase. Toward their margin, they are generally made up almost entirely of dull white feldspar—mostly oligoclase—toward the center, corundum makes its appearance, along with silvery white margarite, and in places these two minerals occur to the exclusion of the feldspar. In some places they are entirely feldspathic, in others rich in corundum—locally carrying as much as 60 per cent. of that mineral, besides the margarite which has been derived from corundum. They appear to be richer in corundum near their apexes, where they run as nearly horizontal sheets. Accessory minerals are fuchsite mica in patches, and black tourmaline in nodules, mostly near the center of the dikes and associated with the corundum.

> The most instructive of the dykes pierces the largest body of serpentine . . . . being flanked by the granulite below through a vertical range of fully 150 feet. In this lower part it is a normal pegmatite with quartz, white orthoclase and subordinate plagioclase, but hardly any biotite and no corundum. Yet in the serpentine above, where it has contracted and is only a few feet wide, it has lost all of its quartz but now carries corundum; these variations are particularly illuminating (5, p. 55).

The serpentine "has at the immediate junction been converted for a short, though variable, distance into a rock composed wholly of brown flaky mica, and this in turn passes laterally into a proportionately wider belt of talc, the width of this double belt of alteration of serpentine ranging from a few up to 10 feet at most, the serpentine beyond being unchanged" (5, p. 56). Isolated veins of crystalline talc with sharp boundaries up to 15–20 centimeters cut the serpentine. Irregular to lenticular patches and strips of phlogopite rock are to be found at many places within the aplite.

Northern and Eastern Transvaal.—The corundum deposits of northern and eastern Transvaal have recently been well described by Hall (8) whose excellent concise descriptions and discussions defy abridgement without omitting data pertinent to the origin of the deposits. The main producing area is roughly rectangular, 33 by 54 miles in extent. The oldest rocks of the region are schists of basic character and largely of igneous origin, but associated in flows with true sediments or with massive serpentine, pyroxenite and hornblendite. These old rocks are found only as small bodies and are surrounded by and intruded by granite and granite gneiss. The granite gneiss and the basic schists are in turn intruded by pegmatites made up of plagioclase and quartz, with scattered nests of muscovite. These pegmatites are believed to be genetically associated with the Palaboro plutonic complex. This latter is found only in the Low Country and is made up of granite, syenite, pyroxenite and intermediate types. Basic dikes cut the other rocks.

The corundum occurs in plumasite (corundum-plagioclase) dikes. Hall (8, pp. 129–30) summarizes the field relations as follows:

(*a*) All reef occurrences are closely associated and in most cases in visible contact with some form of basic rocks, more often massive than schistose, belonging to the serpentine, pyroxenite, peridotite, or hornblendite families.

(*b*) The corundiferous rocks generally occur as more or less vertical dyke-like bands up to several feet or yards thick, intrusive in the basic rocks; exceptionally the form is that of a vertical plug up to 40 or 50 feet in diameter (Palmietfontein).

(*c*) A casing ("vermiculite" zone) of the reef is almost invariably present as a thin veneer of soft highly micaceous or talcose material.

(*d*) The margin of the country formation shows a narrow zone of contact alteration, commonly due to more or less fibrous or flaky talcose matter.

(*e*) The characters of the reefs in the Plateau region and the transition belt are those of coarsely crystalline plumasite or plumasite pegmatite, rich in plagioclase and carrying coarse scattered crystals of commonly pale-gray corundum with more or less idiomorphic outline and frequently accompanied by irregularly distributed biotite. In the Low Country region the reef is more often composed essentially of margarite and corundum, felspar being much less in evidence; this is the *marundite* type of reef.

(*f*) The so-called "boulder" corundum of the Plateau region and the transition belt is identical in origin with plumasite, but is more resistant to weathering owing to the higher content in corundum and smaller proportion of plagioclase, which is often altered to a far greater extent than in the case of the normal plumasite reef; hence the frequent occurrence of this form of corundum in loose blocks. In the Low Country "boulder" corundum is practically indistinguishable from the prevalent type of margarite-carrying reef.

Hall's descriptions of individual deposits and his numerous, excellent illustrations bring out the points made in his summary and some additional features of interest.

Some deposits show successive layers of plumasite and the vermiculite zone (8, p. 65, Fig. 3). In some of the dikes, the corundum is distributed throughout, but in many it is concentrated along the borders near the contact with the basic rocks (8, p. 75, Fig. 5, and p. 101). This plumasite carries more biotite than is common. Less commonly a corundum-rich layer is present in the interior of the dike (8, p. 79). An analysis of the boulder corundum zone of such a deposit gave 36 per cent. corun-

dum and 52 per cent. andesine. In another deposit the central portion of the plumasite is more friable and richer in biotite.

Some of the dikes of plumasite are associated with quartz-feldspar pegmatite (8, p. 113). At the Birdcage camp pegmatite appears to grade into plumasite along the vein and another body has a layer of plumasite along one contact. One reef (8, p. 118) is made up of three zones, each of distinct mineralogical composition, but not marked off by any structural feature; an outer or contact zone of plumasite, an inner zone of feldspar without corundum, and a central zone of quartz-feldspar pegmatite. In one deposit (8, p. 105, figure) plumasite occupies the center, and is separated from the serpentine on both sides by a layer of pegmatite. A thin casing of biotite separates the plumasite from the pegmatite. Another (8, p. 101, figure) shows the pegmatite on only one side of the plumasite. The pegmatite is separated from both the plumasite and the pyroxenite by a rather broad layer of biotite.

In one deposit (8, p. 126) the dike is made up of disthene, corundum, green mica, biotite, and plagioclase in variable proportions. Lenses of disthene rock are in the vermiculite layer and the granite contact is parallel to the dike but separated by a layer of hornblendite. In another deposit the hornblende pyroxenite next the plumasite is a soft, dirty yellowish, serpentinous decomposition product with much sillimanite. A fragment lying between the plumasite and overlying country rock is made up of corundum and sillimanite.

North Carolina and Georgia.—The corundum deposits of North Carolina and Georgia have been studied in detail and carefully described by Pratt and Lewis (9), King,[3] Chatard (3) and Cobb (4). They resemble the deposits of Natal but occur mostly along the contacts between peridotites, and gneisses and schists, and the veins carry little feldspar. The following description is taken largely from the bulletins of Pratt and Lewis.

The corundum deposits are closely associated with compara-

[3] King, F. P., "A Preliminary Report on the Corundum Deposits of Georgia," Geol. Surv. of Georgia, Bull. 2, 1894.

tively fresh peridotites and related rocks, mostly dunite (olivine rock) which intrude a complex made up chiefly of biotite gneiss and to a less extent of hornblende gneiss, mica schist, and quartz schist. Dikes of amphibolite cut the peridotite. The corundum is in vein-like bodies, partly between the gneisses and the peridotite, and partly in the peridotite. The veins within the peridotite trend approximately toward the center of the mass, generally growing gradually narrower in that direction. The border veins show no marked tendency to thin out in any particular direction and they branch into the peridotite.

An interior vein was exposed in a shaft near the southern part of Corundum Hill for a distance of 20 to 25 feet, exhibiting the following cross-section, from either side toward the center.

1. Normal dunite.
2. Dunite, somewhat friable and discolored, passing into 3.
3. Fibrous talcose rock, merging into 4.
4 Grayish enstatite,[4] somewhat fibrous.
5. Green chlorites, 6 to 15 inches in thickness.
6. Central corundum-bearing zone, consisting of chlorites, corundum, and spinel, 6 to 8 feet thick.

The symmetry of the vein is very marked, the different zones of minerals being encountered in the same order and in approximately the same thickness in approaching the central corundum-bearing zone from the dunite on either side. In these characteristics the cross-section given above is typical, being the same in all the interior veins examined.

Sometimes, instead of the talcose rock (3 in above cross-section), serpentine may be the limit of the vein next to the dunite. In one of the interior veins at Corundum Hill, near the west side of the outcrop, the corundum-bearing chlorite and vermiculite zone is in direct contact with serpentine on both sides. The zone is also divided and almost pinched out in one place by the serpentine.

An important variation from the normal modes of occurrence with peridotite, as just described, which has been observed at a number of localities, is the development of a zone of corundum-bearing plagioclase. This is found either in the corundum-bearing zone of chlorites and vermiculites (6 of above cross-sections) or entirely replacing these zones. The feldspar, in the specimens determined, is a basic lime-soda species, is sometimes fine grained and compact, at others very coarsely crystallized, and varies, in different localities, from a few inches to several feet in thickness. In addition to the corundum it is found to contain, in different

[4] Mr. C. S. Ross informs me that this mineral is anthophyllite.

localities, large masses of zoisite, coarse black hornblende, and other minerals.

An interior plagioclase vein at the Hamlin mine, on the headwaters of Ellijay Creek, in Macon County, contains a band of pegmatite, 4 inches thick, as its central member, and not bearing corundum, so far as observed (8, p. 201–4).

Spinel is found at a number of corundum mines and in a few places it is intimately associated with corundum and chlorite.

In regard to corundum veins in pyroxenite, Pratt and Lewis say:

At many of the corundum-bearing peridotite localities in Macon, Jackson, and Transylvania counties, a pyroxenite composed of interlocking coarse-bladed enstatite constitutes an important part of the outcrop; and at a number of places the pyroxenite alone forms oval and lenticular masses in every way similar to those composed of peridotite. In both cases, corundum-bearing zones of secondary minerals are frequently formed along the borders of the pyroxenite, intersecting the mass of the rock in exactly the same manner as described above for peridotites (9, p. 206).

Where the corundum veins are in amphibolite the section of the veins is approximately as follows: "A central feldspar vein that is sometimes encountered more or less altered to kaolin and often bearing corundum." On both sides of it are the vermiculite zones carrying corundum. Beyond are radiating sheaths of actinolite (8, p. 209–10).

Where the corundum vein lies between the gneiss and the peridotite, the border zones next the peridotite are like those of the interior veins but those next the gneiss are narrower, less regular and of different character. Next the corundum is a zone of chlorite and beyond, next the schist, a zone of yellowish vermiculite. Both these zones are narrow and irregular and either one or both may be absent.

In all of these peripheral or border veins the plane of contact between the hydrous secondary minerals and the gneiss is very sharp and distinct. The minerals developed between the corundum-bearing zone and the peridotite are invariably in greater abundance, and differ in character from those between this zone and the gneiss (9, p. 202).

Cobb (4, p. 27) states: "In places the dunite and gneiss show a clean line of contact with fresh dunite against fresh gneiss." In places a border zone similar to that between the dunite and corundum veins separates the fresh dunite from the gneiss.

In places veins of feldspar or feldspar and quartz cut the dunite. Cobb (4, p. 27) states:

> The feldspar dikes are separated from the peridotite by a narrow contact zone, similar to that occurring with the corundum, which does not appear in the contact with the adjacent gneiss. When there is a small amount of quartz with the feldspar a still narrower contact zone is present. When the quartz reaches a considerable amount no contact zone appears.

According to Pratt and Lewis, corundum is present as an accesssory mineral in some of the amphibolites, anorthosites, and pegmatites of the region and has been found in peridotite, pyroxenite, and other igneous rocks.

In the North Carolina corundum area, corundum is also found in the gneisses usually associated with white or dark mica, garnet, or cyanite. In many of such occurrences it seems to be closely associated with peridotite intrusives. In the southeastern part of Clay County, N. C., corundum has been found in quartz schists composed mostly of quartz and biotite mica, with more or less garnet. Corundum in amphibole schist has been described from the Sheffield mine, in Cowee Township, Macon County.

Pennsylvania and Maryland.—At a number of places in Lancaster and Chester counties, Pennsylvania, and Cecil County, Maryland, particularly Sylmar, Pennsylvania, and Conowingo, Maryland, feldspar has been mined from dikes of albitite. These dikes have been described by Hopkins,[5] Bastin,[6] and Gordon (7).

I spent several days in the field examining the albitites near Sylmar, and at Brinton's Quarry, near West Chester. The following description is partly abstracted from Gordon's paper but is partly the result of my own observations in the field and laboratory.

[5] Hopkins, T. C., "Clays and Clay Industries of Pennsylvania," Part 2. Appendix to Ann. Rept. Pennsylvania State College for 1898–99.

[6] Bastin, E. S., "Economic Geology of the Feldspar Deposits of the United States," U. S. Geol. Survey Bull. 420, 1910, pp. 63–77.

The soda pegmatites or albitites cut serpentines that are early Cambrian or older, and range in size from a few inches in width to great masses four to five hundred feet in length, and more than a hundred feet in width. They are very irregular, pinching and swelling and frequently bifurcating. Where I observed them the irregularities are not due to curved boundary surfaces but to the meeting of nearly plane surfaces in sharp angles. Horizontal sections of two of the bodies are shown in Figs. 1 and 2.

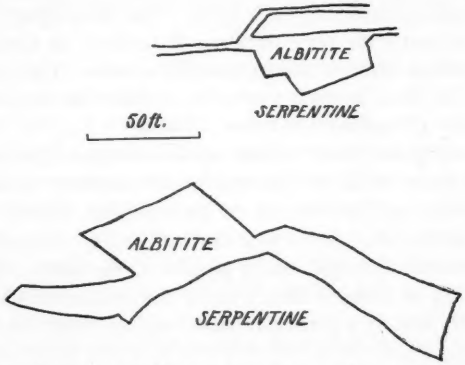

FIG. 1. (Top) Plan of albitite body two miles northwest of Sylmar, Penn.
FIG. 2. (Bottom) Plan of albitite body 1¼ miles northwest of Sylmar, Penn.

The walls are nearly vertical and the bottom is covered with loose rock. Judging from the way the quarries were stopped at shallow depths, it seems probable that the bottom of the albitite is also nearly a plane surface. This angular form is characteristic of all the large bodies of albitite that I visited.

The filling of the veins is said to have been almost entirely of feldspar (albite-oligoclase) with a little hornblende, biotite and muscovite, and locally garnet. Tourmaline is abundant locally in the albitite of Brinton's quarry and molybdenite has been found northwest of Sylmar. The albitite of Wiant's quarry, northeast of Pilot, is filled with miarolitic cavities lined with albite crystals

on which crystals of beryl are rarely implanted. The texture of the albitite is even granular and the grains are commonly a few millimeters in cross section, but in places the feldspar and biotite are a decimeter or more across. The coarser textured rock was seen chiefly in small lenses and these small lenses commonly carry more biotite.

On both sides of the albitite bodies and separating them from the serpentine, there are three distinct layers. In passing from the albitite to the serpentine their order is: (1) vermiculite layer, (2) amphibole layer, (3) talc layer. The three layers are commonly of nearly the same thickness or probably as Gordon says, the amphibole layer is thinner than the others. The total thickness of the three layers is somewhat variable but they are rarely much over 18 inches or less than 6 inches.

The vermiculite layer is made up very largely of a vermiculite derived from biotite or phlogopite but contains more or less fluorapatite, and locally talc or anthophyllite. Very rarely a green chlorite takes the place of the vermiculite. The mica plates are commonly arranged nearly parallel to the walls. The mica plates vary in cross section from a few millimeters to several decimeters and in a particular place they are likely to be rather uniform.

The amphibole is sharply separated from the vermiculite. It is commonly made up, where fresh, almost entirely of cross columns of anthophyllite with about 10 per cent. of iron as shown by the following optical data: Opt.—, 2V near 90°, Z ‖ elongation, $\alpha = 1.608$, $\beta = 1.625$, $\gamma = 1.635$. In places it contains more or less vermiculite. In the dike on the north slope of the northwest point of Brinton's quarry, near West Chester the amphibole is tremolite. In all places the amphibole is more or less altered to talc and serpentine and locally it is almost completely altered.

The talc grades into the amphibole on the one side, and into serpentine on the other. It is made up mostly of talc but in places contains remnants of amphibole, and it also carries some chlorite or vermiculite and magnetite. It is partly, and may be largely, derived from the amphibole.

The serpentine contains some colorless chlorite, commonly some tremolite, rarely anthophyllite and in most places some talc. The amphiboles are mostly altered to serpentine.

Bastin states that the Brandywine Quarry, about 1½ miles northwest of Sylmar, Maryland,

> is 200 feet long, 70 to 80 feet wide, and 90 to 100 feet deep, the greatest length being in a direction N. 10° W. The feldspar constitutes a single dike, which is about 12 feet wide at the south end of the pit, but broadens toward the north end. The wall rock is serpentine and the contact is marked by a zone, about 1 foot thick, of blue green talc, now much decomposed."[7]

He describes a similar condition for the Sparvetta Quarry, about half a mile to the south.

About many of the albitite bodies and particularly about that shown in Fig. 2, are veinlets of biotite-amphibole and talc which penetrate for many feet into the serpentine. Some of the veinlets are a foot wide and have centers of vermiculite, flanked first by bands of amphibole, and then by talc, the width of which does not differ greatly from that of similar bands flanking the main albitite bodies. Usually, narrower veinlets lack the central vermiculite band and some narrow ones contain only talc. One tapering veinlet shows vermiculite first pinching out, and finally the amphiboles.

The albitite dikes are especially well shown in Brinton's Quarry, about three miles south of West Chester, Pennsylvania. Here the serpentine was quarried many years ago, and three large openings give unusual opportunities for the study of the serpentine and associated albitite.

Small bodies of albitie are found, chiefly in the walls of the northwest quarry pit. On the east wall of this pit, a vein carrying a lens-like body of albitite up to three feet across extends from the floor to the top of the pit. The albitite consists chiefly of oligoclase with considerable vermiculite, on both its borders it grades into nearly pure vermiculite a few inches across. Next, is a six-inch band of coarse crystals of anthophyllite and grading into this,

[7] Bastin, E. S., *Op. cit.*, p. 69.

is a layer of talc about four inches thick. The talc grades rapidly into the serpentine. The central feldspar may be absent.

A section from the side to the center of this dike, where there is no feldspar, but where the other bands, especially the vermiculite, are thicker than usual, is:

Thickness, inches.	
	Serpentine.
1	Talc and tremolite with some chlorite.
8	Talc, tremolite, and vermiculite in about equal amounts, with some chlorite and serpentine.
3	Similar to above but with less tremolite.
3	Anthophyllite partly altered to talc.
2	Vermiculite in crystals a few millimeters across.
8	Coarse vermiculite with some apatite and locally tourmaline.

The amphiboles are much altered to talc and serpentine and there is an unusual amount of tremolite.

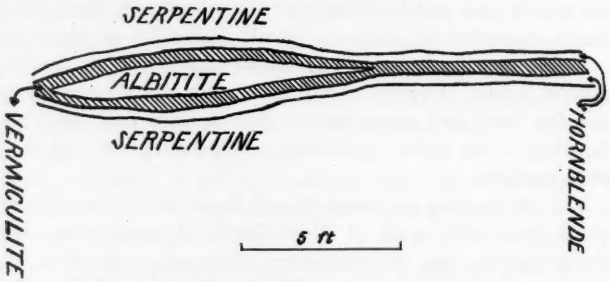

FIG. 3. Section of vein in Brinton's Quarry, near West Chester, Penn.

Across the quarry floor on the south side and about in line with the dike described above, there are two dikes about twenty feet apart. A rough sketch of the eastern of these two dikes is shown in Fig. 3, and a section across it is:

Thickness, inches.	
	Serpentine.
1	Anthophyllite cross fiber with some talc, chlorite, and serpentine.
3	Talc, vermiculite, and anthophyllite.
2	Coarse vermiculite with some feldspar and chlorite.
14	Albitite with some large vermiculite plates.

Beyond, the zones next the albitite are repeated. The west dike is rather uniform in width and has clean cut, regular walls for the twenty feet of vertical exposure. The central part is about fifteen inches across and is made up of vermiculite with some feldspar. On both sides of this is a layer of talc about five inches thick and beyond that is serpentine.

Between these two dikes the serpentine is traversed by a network of irregular veinlets mostly only a few inches across and made up of vermiculite, amphibole, talc, with rarely a little feldspar in the center.

To the east of the dikes, on the east wall of the quarry, the serpentine for about twenty feet along the cliffs and from top to bottom is bleached and traversed by numerous roughly parallel veinlets of mica and talc. These veinlets which are mostly only an inch or two across are rarely over a foot apart.

Along the west face of the middle quarry, extending for 100 feet northwest from the southwest corner, and for the height of the quarry face, the serpentine is cut by a complicated network of veinlets from a few inches to three feet wide; few of the intervening serpentine areas are over a few feet across, and in places only small rounded remnants of serpentine are left. The veinlets have centers of vermiculite, bordered by amphibole, and next by talc. In a few wide places there is a little feldspar in the mica zone, and in one place where a vein is unusually wide a lens of coarse crystals of feldspar is in the center of the mica zone.

This and the other networks of veinlets show clearly that the rock was shattered and the veinlets were formed after the serpentinization had taken place; otherwise these minute veinlets would surely have been broken or displaced and would show some effect from the serpentinization.

On the ridge between the middle and southeast quarries, is an interesting dike that is considered by Gordon to show most clearly the origin of the albitites as desilicated pegmatites. It resembles the dikes in Finland described by Saxen (10). It is exposed for about 100 feet and varies in width, from seven feet on the south side of the quarry to almost nothing on the north side. It is

bordered on both sides by the usual zones of vermiculite, anthophyllite, and talc. These zones are about a foot wide, regardless of the width of the dike.

The central part of the dike, where it is wide, is a nearly white rock of aplitic habit and consists chiefly of quartz, sodic oligoclase and microcline in about equal proportions, with a very little biotite and several per cent. of muscovite, probably secondary. Where the dike is only one and one-half feet wide the central part is somewhat similar but lacks quartz, has more oligoclase and the plagioclase is much altered. Where the dike is six inches wide the center is an altered albite-microcline rock.

A section across the dike near the road where it is about 5 feet wide is shown in Fig. 4.

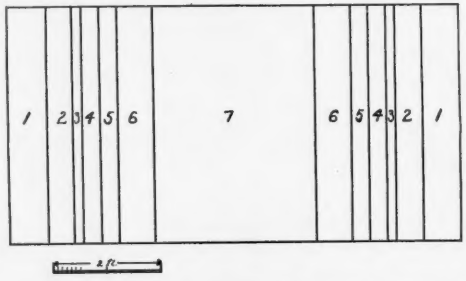

FIG. 4. Cross section of the "Pegmatite" vein in Brinton's Quarry, near West Chester, Penn. 1. Serpentine. 2. Talc. 3. Vermiculite and talc. 4. Vermiculite. 5. Sodic oligoclase with some tourmaline. 6. Aplitic rock made up of microcline and albite with little quartz. 7. Aplitic rock made up of about equal amounts of microcline, albite, and quartz.

Near the south side of the quarry there is in the dike an angular block, exposed for several feet, of nearly pure granular quartz of pegmatitic habit. It is sharply separated from the pegmatite of the dike but near its border it is mostly albite and is rimmed in part by a narrow seam of black tourmaline or by a narrow zone of albite impregnated with tourmaline.

Ostravaaragebietes, Finland.—Pegmatites and albitites much

like those of Pennsylvania have been described by Saxen (10) from Ostravaaragebietes, Finland. Dikes of microcline granite-pegmatite cut a tremolite-serpentine rock and are separated from the serpentine by three zones, similar to those described by Gordon (7) from Pennsylvania. Next to the pegmatite is a layer of biotite which carries some black tourmaline, beyond that is a layer of actinolite, and next to the serpentine is a layer of chlorite. Here and there veins and small bunches of black tourmaline cut the actinolite and chlorite layers but rarely the biotite layers. In small dikes, the central pegmatite has no quartz and is made up chiefly of granular oligoclase with some colorless mica and a little tourmaline, chlorite, and clinozoisite; in wide ones, the central part is ordinary microcline granite-pegmatite and the borders are oligoclase rock.

Resumé of Descriptions.—The preceding descriptions show that the plumasite dikes of Natal, Eastern Transvaal, the Urals, and Pennsylvania, the albitite dikes of Pennsylvania and Maryland, and of Ostravaaragebietes, Finland, and the corundum veins of North Carolina and Georgia, have the following important features in common:

1. All are irregular, dike-like, or vein-like in form.

2. All of them cut peridotite, pyroxenite, or related rocks lacking or low in feldspar and feldspathoids, and with few exceptions, very low in silica and alumina, and high in magnesia. Where they cut serpentine they appear to be later than the serpentinization. In North Carolina and elsewhere the dikes tend to lie along or near the contact of the ultrabasic rock.

3. Quartz is rare in the deposits and the feldspar is almost entirely plagioclase, usually high in soda but occasionally high in lime. Corundum is present in greater or less amount in many of the veins or dikes, and it is the chief mineral in some. Phlogopite, biotite or vermiculite are abundant in some feldspar-poor dikes. Muscovite is common in the albitites, where it is probably secondary. Margarite may be rather abundant, but it is in considerable part derived from the corundum. Diaspore is not uncommon, and is in part later than the feldspar and corundum.

Garnet tourmaline, zoisite, spinel, hornblende, and other minerals are present in some of the deposits.

4. Some of the dikes show a central part of aplite or pegmatite made up of quartz, potash feldspar, and sodic plagioclase, with borders of nearly pure sodic plagioclase and in places an intermediate layer of potash feldspar and sodic albite. In other deposits the center is nearly pure plagioclase and the borders are rich in corundum. In one deposit the center is pegmatite, an intermediate zone albite, and the border is albite-corundum rock. In some bodies the arrangement is less regular and the corundum may be concentrated in the center or elsewhere.

5. Almost invariably the ultrabasic rock adjoining the veins has been altered for a variable distance from the dikes, while gneisses and schists adjoining the veins have been little altered. This alteration is commonly arranged in definite and regular zones and, where both walls are ultrabasic rock, these zones are essentially the same on both sides of the veins. The zone next to the peridotite or serpentine is in most deposits talc, while the zone next to the vein or dike is phlogopite, biotite, chlorite or their alteration product vermiculite. An intermediate zone is actinolite or anthophyllite. The chemical changes that took place in the replacement of the peridotite, pyroxenite, or serpentine are, therefore, a large addition of alumina and potash and, in some, water, for the zone next the vein; and an addition of silica and in some cases water for the zone next the peridotite.

6. There seems to be little relation between the width of the albitite or plumasite dike and the width of the bordering layers of vermiculite, amphibole, and talc. In the Pennsylvania area the three layers together are commonly between six and eighteen inches thick though some are greater or less. In a given dike the width of these layers varies only moderately from place to place, though the albitite may vary from nothing to many feet. In many of the veins the albite is lacking, and this is especially well shown in Brinton's Quarry, where a network of veins with centers of vermiculite and outer layers of anthophyllite and talc cut the serpentine, whereas albite is found only locally where the

veins are unusually wide. In general as the veins become narrower, first the albitite pinches out, then the mica layer, and finally the amphibole.

7. The bordering layers appear to be about the same both in thickness and character about a dike of nearly pure albite, a dike made up of albite and corundum, or a dike made up largely of corundum.

8. The descriptions indicate also that these bordering zones are about the same whether the country rock is serpentine, nearly pure olivine rock, or pyroxenite, and that there is no great difference when the country rock is amphibolite. However, where one wall of the plumasite is granulite, schist, or other feldspar or quartz bearing rock, the bordering layers on that wall are much narrower and of a different kind.

9. In the South Carolina area, corundum is also found in some of the schists and gneisses near the peridotite intrusives, and in some of these occurrences the corundum is disseminated in the schists and gneisses next the contact with the pyroxenites.

10. In Natal a single dike was observed by du Toit (5, p. 55) to be a normal pegmatite with quartz, orthoclase, and subordinate plagioclase but hardly any biotite and no corundum where it cut the granulites, but where it cut the serpentine it becomes narrower, carries no quartz but contains corundum.

ORIGIN OF THE OPEN SPACES.

The sharp contacts of the Pennsylvania albitite bodies and their irregular angular shape seem to indicate that they filled open spaces. The irregular angular form of the bodies, as illustrated by Figs. 1 and 2, indicates that the fractures were formed by the displacement of blocks in a zone of fracturing. The zones of fracturing, associated with the albitite bodies in Brinton's Quarry and elsewhere, support this view.

ORIGIN OF THE ALBITITE AND PLUMASITE.

Before entering into a discussion of the origin of these deposits it is necessary to reach an understanding of the use of the terms.

It is now generally recognized that, in common with many geological phenomena, there is no sharp distinction but rather every gradation between granitic rocks, pegmatites, hydrothermal deposits, thermal contact metamorphic deposits, and hydrothermal contact metamorphic deposits. The chief factors in determining the deposit to be formed are believed to be composition and temperature of the solution, though rate of cooling (determined chiefly by the temperature, etc. of the adjoining rocks, including air and water) and the ease with which a part of the material may escape from the system, as well as interaction between the solution and adjoining bodies, may be important in some deposits. Their influence would, for the most part, affect chiefly the temperature and composition of the solutions. Pressure, except for deep seated deposits, probably influences the deposits chiefly by preventing the escape of the volatile constituents and influencing the texture and to some extent the mineral composition of the resulting rock.

In general, the granitic rocks form at relatively high temperatures (not far from 700° C.) from magmas with low content of mineralizers (only a few per cent.), including under that term all those constituents that are present in the magma at the time of the intrusion but are not retained in the completely crystallized rock.

Typical pegmatites form at considerably lower temperatures and from magmas with higher content of mineralizers yet within such limits that the magma crystallizes in place and the solidified rock has essentially the chemical composition of the magma from which it crystallized. Both du Toit and Gordon appear to have used pegmatite in this sense.

Hydrothermal veins, including the so-called pneumatolitic veins, form at temperatures ranging nearly or quite as high—possibly higher—than those of pegmatite to relatively low temperatures. They contain more mineralizers than the pegmatites and they are formed by solutions passing along and depositing one or more of their constituents, while the bulk of the solutions pass on, carrying with them more or less material abstracted from the wall

rock. In some cases they may be relatively concentrated solutions, in fact they grade into pegmatites. In these and in the pegmatites the mineralizers are probably in part, at least, combined with the rock constituents (water may be combined with SiO_2, or other constituents) and the conditions are very different from those of a dry melt, on the one hand, and those of a solution of silica, silicates, alumina, etc. in water, on the other.

Hydrothermal contact metamorphic rocks are a special kind of hydrothermal replacement deposits and form at temperatures just below those of the granitic magmas and probably in about the same range as the pegmatites, though in the later stages of contact metamorphism the temperatures may be much lower. They are formed from moving solutions which are very different in composition from the rocks they form or even from the constituents they add to the rocks, as much of their material passes on. However, they no doubt carry a much higher content of SiO_2 and the metallic oxides than do water solutions.

Thermal contact metamorphic rocks form at temperatures up to and just below magmatic temperatures and they crystallize from solid rocks with little movement of material and with the solution of only a very small part of the material at a time.

Origin from Desilicated Pegmatites.

General Statement.—The theory of desilicated pegmatites, would seem to require direct magmatic reaction between the molten pegmatite magma and the bordering serpentine or other ultrabasic rock in what was essentially a closed system. The material removed from the pegmatite should therefore be approximately equal to the material added to the ultrabasic rock.

To form an albite rock from an ordinary pegmatite a large amount of silica must be removed, and much K_2O and Al_2O_3 in molecular proportions. To form the maximum amount of plumasite (corundum-albite rock) much silica must be removed, and nearly as much potash by weight as there is corundum in the plumasite.

Evidence Favoring the Theory.—The theory that the deposits

under discussion were formed by the desilication of pegmatites by reaction with a wall rock of peridotite or related ultrabasic rock was first proposed by du Toit, was later elaborated for the American occurrences by Gordon (7), and has been accepted by Hall (8), Cobb (4), Saxen (10) and Fersman (6). All the authors clearly had in mind "normal" pegmatites that had crystallized in place from magmas. The process must have been that recently discussed by Bowen (2) in his paper on "The Reaction Principles in Petrogenesis."

The evidence presented favoring the origin of the albitites and plumasites from desilicated pegmatites is:

1. They are invariably associated with ultrabasic rocks.

2. They are invariably bordered by zones of altered ultrabasic rock. These zones have higher SiO_2 content than the ultrabasic rock. They also carry more Al_2O_3 and K_2O.

3. They are not uncommonly associated with normal pegmatites. Hall (8) describes these pegmatites as mostly near the center of the vein but in some veins at the borders, where they are commonly next the ultrabasic rock and separated from the plumasite by the vermiculite zone. Gordon (7) and Saxen (10) describe pegmatites with regular border zones of albitite. Du Toit (5) states that one dike is a normal pegmatite where it cuts granulite and a plumasite where it cuts serpentine.

As to the Natal plumasite, du Toit (5, p. 56) says: "The only adequate hypothesis is that of desilication whereby the original acid magma could have become supersaturated with alumina." He considers as sufficient evidence for this the facts that corundum is confined to those aplites that cut the serpentine and the alteration of the serpentine adjoining the dike.

Hall (8, p. 191–200) concluded that the Transvaal deposits had an origin similar to that proposed by du Toit for the Natal deposits. However, the two districts have some differences. In Natal the basic rocks intrude the granulites while in the Transvaal the basic rocks represent inclusion in the granitic gneiss. He states:

> The separation of corundum is clearly due to the magma being super-

saturated with alumina . . . there are only two alternatives left to account for this supersaturation; either certain portions of the parent magma contained a local excess of alumina, or this was brought about through a change in the relative proportions of some constituents under the influence of the magnesian country rock.

Nothing was found to support the view that the corundum reefs are supersaturated highly aluminous portions of their parent magmas, but there is a good deal of evidence pointing to the excess of alumina being dependent on abstraction of silica.

It is a remarkable fact that so long as a pegmatite remains in granitic or gneissic country rocks, it does not develop corundum, but becomes corundiferous when intrusive in the basic magnesian rock.

Also, there is frequently a marked bilateral symmetry in the reefs, the corundum being distributed with reference to its proximity to the planes of contact, along which there are more crystals than in the interior portions; these may be even quite free from that mineral so as to consist of a purely felspathic zone. . . .

It is therefore believed that the corundiferous rocks originated as pegmatites, derived from the granite-gneiss magma; where these intruded basic magnesian rocks, the proportion of silica became reduced and mainly consumed in changing magnesian silicates of the country rock into talc. Where this has gone far enough, saturation of the reef with alumina and finally supersaturation with that oxide result; at this stage alumina separates as corundum. Such a process is not exactly parallel to contact metamorphism, and is more correctly described as contact metasomatism. It is highly significant, that not a single instance was observed in the field or in the large number of thin sections examined, of a direct association of corundum with quartz.

. . . . . .

Another aspect of the genetic problem concerns the "venue" of the intrusion. Where there is a marked bilateral symmetry with an increase in the amount of corundum along the margins, combined with a well-defined casing and contact zone, it is probable that the formation of corundiferous rocks took place more or less *in situ*. These features seem to be most evident in thin or moderately thick intrusions, when the theory of removal of silica under contact metasomatic conditions does not demand too high a scale of operations. In exceptional cases, like that of the Palmietfontein reef, where the plumasite is extremely coarse, carries large crystals of idiomorphic corundum, and is some 40 feet thick, it is difficult to realize how the removal of silica should have been so thorough throughout the reef, if it occurred *in situ*, because one is entitled to expect, that irregular patches should have remained, specially near the central portions of the reef, still composed of quartz-feldspar rock, as is actually sometimes

seen in other workings, e.g. Rainbow Camp. Nothing of this sort could be observed at the Palmietfontein Mine, and exposures are not good enough to decide how far a contact zone has developed in the country rock. The genetic history of the Palmietfontein reef is probably the same, but the ore body reached its present position after it had already acquired an excess of alumina. With such a view the thin veneer of micaceous material need not be inconsistent, because a slight additional contact metasomatic effect is not excluded.

Hall (8, p. 198) gives the following summary of the genetic theory:

(*a*) The reefs originated as pegmatitic derivations of the granitic magma.

(*b*) While intrusive in the basic magnesian rocks, they became supersaturated in alumina, which caused this excess to separate as corundum, leaving the balance as feldspar (plumasite).

(*c*) Supersaturation came about through removal of silica, which converted the wall rock into talc along a "contact" zone; at the same time certain other constituents, *e.g.*, potash, were supplied to form the micaceous veneer or "casing" of the reef.

(*d*) Subsequent magmatic changes—possibly under pneumatolytic conditions—changed the corundum-felspar reef (plumasite) into a margarite-felspar body—marundite.

(*e*) In most cases the genetic cycle occurs *in situ*, in a few it belongs to the pre-intrusive period.

Evidence Opposing the Theory.—The evidence opposing the theory of desilicated pegmatites will be presented under the following divisions:

1. The width of the reaction zones is greater than we are accustomed to see and is greater than we would expect.

2. The mineral assemblages of the reaction zones are those of hydrothermal origin rather than of magmatic origin.

3. The minerals of the pegmatites are not such as would be expected from the desilication of a pegmatite or the reaction of a pegmatite with an ultrabasic rock.

4. The amount of material that must be removed from a pegmatite to make an albite rock or an albite corundum rock seems excessive.

5. There is no relation between the width of the border zones and the width of the albitite or plumasite.

6. The material added to the border zone is quantitatively very different from the material taken from the pegmatite.

7. Some of the pegmatites associated with the plumasites are later than the plumasites.

Width and Minerals of Reaction Zones.—The amount of reaction between the wall rocks and the pegmatite would seem to be excessive, as pegmatites commonly show little or no reaction with the adjoining rocks even where they cut gabbro or limestones. The biotite zone next the pegmatite would fit Bowen's (2) reaction principle but taking the reaction zones as a whole (biotite, anthophyllite or actinolite, and talc) they indicate a hydrothermal rather than an igneous origin.

Reactions Required.—The removal of SiO_2 from a pegmatite would first decrease the quartz and after all the quartz was gone, would next change the albite to nephelite. For the development of albitites all the free SiO_2 must have been removed and in addition all microcline ($K_2O.Al_2O_3.6SiO_2$). This might be done by the reaction of the pegmatite magma with a magnesia rich rock (the ultrabasic rock) and the development of talc, anthophyllite and biotite. These minerals are present in the reaction zone so that the development of the albitites from the reaction of a pegmatite on an ultrabasic rock is qualitatively reasonable.

For the corundum bearing rocks the reactions are much less reasonable. It is generally recognized by petrographers that under magmatic conditions K_2O combines with Al_2O_3 to form feldspar, leucite, mica, etc., if Al_2O_3 is available. This experience of petrographers with natural rocks is in agreement with laboratory experiments of Morozewicz,[8] who concluded that the crystallization of corundum and spinel depends not on the "basicity" of the magma, but only on the ratios of the bases (Na_2O, K_2O, CaO) to alumina. The equilibrium diagrams for Na_2O–Al_2O_3–SiO_2 and K_2O–Al_2O_2–SiO_2 have not been published but that for

[8] Morozewicz, Josef, "Experimentelle Untersuchengen über der Bildung der Mineral im Magma," *Min. Pet. Mitt.*, XXVIII., 1–90 and 107–240, 1890. Also Abstract, *Jour. Geol.*, VII., 300–315, 1899.

$CaO–Al_2O_3–SiO_2$ shows that corundum can be formed with a small excess molecularly of CaO over Al_2O_3.[9] For the $MgO–Al_2O_3–SiO_2$ system corundum does not form if MgO is in excess molecularly over the Al_2O_3.[10] These diagrams confirm Morozewicz's experiments but it must be remembered that none of the laboratory experiments closely reproduce the conditions of the formation of the plumasites as the temperatures of crystallizations of the plumasites were many hundreds of degrees lower than 1380°, the lowest temperature at which corundum was formed in the $CaO–Al_2O_3–SiO_2$ system, and 1575°, the lowest temperature at which it was formed in the $MgO–Al_2O_3–SiO_2$ system. The water and other mineralizers, no doubt, play an important part in the crystallization of the plumasite.

In order to form the corundum bearing rocks from a pegmatite it would be necessary to separate the K_2O from the alumina, removing the K_2O entirely from the system and leaving the alumina for corundum.

Excessive Material Removed from Pegmatite.—To change a normal pegmatite to an albitite or to a plumasite (plagioclase corundum) or to nearly pure corundum would require the removal of a great part of the material. The changes that would be required are shown in Table I. The percentages are given only in round numbers as the available data is sufficient to bring out only the general character of the changes. Column 1 gives the composition of an ordinary pegmatite; Column 2 the maximum amount of pure albite rock that can be separated from the pegmatite; Column 3 shows the loss the pegmatite must undergo to leave the pure albite rock; Column 4 gives the amount of plumasite with 25 per cent. of corundum derived from the pegmatite, and Column 5 the loss of the pegmatite to form this plumasite. To form the corundum rocks of North Carolina nearly everything but the Al_2O_3 must have been removed from the pegmatite.

[9] Rankin, G. A., "The Ternary System $CaO–Al_2O_3–SiO_2$ with Optical Study by F. E. Wright," *Am. Jour. Sci.*, XXXIX., 1–79, 1915.

[10] Rankin, G. A., and Merwin, H. E., "The Ternary System $MgO–Al_2O_3–SiO_2$," *Am. Jour. Sci.*, XLV., 300–325, 1918.

TABLE I.

COMPOSITION OF A PEGMATITE AND OF THE ALBITITE AND PLUMASITE THAT CAN BE DERIVED FROM IT, TOGETHER WITH THE AMOUNTS OF MATERIAL THAT MUST BE REMOVED TO FORM THE ALBITITE AND PLUMASITE.

	1 Pegmatite.	2 Albitite from 1.	3 Removed.	4 Plumasite from 1.	5 Removed.
SiO_2	75	18	57	18	57
Al_2O_3	14	5	9	14	0
Na_2O	3	3	0	3	0
K_2O	8		8		8
Total	100	26	74	35	65

To form the albitite 74 per cent. of the pegmatite must be removed, provided that only enough soda is removed to balance the small potash content of the albitite. For the plumasite with 25 per cent. of corundum all the soda and alumina remain, but 65 per cent. of the original pegmatite material is removed. To form a nearly pure corundum rock about 86 per cent. of the original pegmatite must have been removed. These figures are the minimum as it seems probable that some soda would have been removed with the potash, and, as will be shown later, much Al_2O_3 has gone into the altered zone so an even greater proportion of the pegmatite must have been removed, where corundum is found. It is difficult to believe that so large a proportion of the magma could react with the wall rock or escape from the system.

Width of border zones vs. width of pegmatite.—In particular, the width of the border zones of biotite, hornblende, and talc should bear a close relation to the width of the bordering albitite or plumasite. This is not the case for the Pennsylvania albitite bodies as observed by myself and as described by Gordon (7) and Bastin, nor does it appear to be true for the South African deposits described by du Toit and Hall (8), nor for the North Carolina deposits described by Cobb (4), Pratt and Lewis (9), and Chatard (3). Indeed, in the Pennsylvania area, the border zones are of about the same width, from six to eighteen inches,

whether the albitite body is five feet across or is represented by a few scattered crystals of albite, or is even entirely absent. The fracture zones in Brinton's Quarry where the mica, hornblende, and talc zones are developed about as usual but where the feldspar is absent, and the lens-like bodies of feldspar in parts of some dikes and the absence of feldspar in other parts, without appreciable change in the border zones, as seen in figure 3, show this clearly. Indeed this fact is conspicuous in the field everywhere.

I believe that this entire lack of relation between the width of the albitite body and that of the border zones shows conclusively that the border zones, at least, were formed by moving solutions. These solutions might have been pegmatitic or hydrothermal.

The bodies described by Saxen (10) seem to show some relation between the width of border zone and width of albitite.

Added Material vs. Subtracted Material.—The border zones are not all alike but in Pennsylvania the average zone has approximately equal widths of vermiculite, anthophyllite, and talc. Taking a zone about one foot (about 10 cm. for each layer), and assuming the zones to be made up of the pure minerals with the formulas ordinarily assigned to them; placing the iron with the magnesia, and assuming that all the MgO came from the serpentine, the calculation of the grams of each oxide in a square centimeter cross section of the zone, and the material required to be added from the pegmatite, are shown in Table II.

TABLE II.

CALCULATION OF THE MATERIAL IN GRAMS ADDED TO THE SECTION ACROSS THE REACTION ZONES, 30 CM. WIDE AND WITH A CROSS SECTION OF 1 CM.²

	SiO_2.	MgO.	Al_2O_3.	K_2O.
Talc Zone 10 cm.	16.7	7.5		
Anthophyllite 10 cm.	18.6	12.4		
Phlogopite 10 cm.	12.1	8.1	3.4	3.2
Total.	47.4	28.0	3.4	3.2
From Serpentine.	28.7	28.0		
Added.	18.7		3.4	3.2

The material added is therefore equivalent to about 19 grams of orthoclase and 6.4 grams of quartz. This could be supplied by the albitization of a layer of pegmatite 16.8 cm. wide and made up of 43 per cent. each of orthoclase and albite and 14 per cent. of quartz and would leave only 7 cm. of albitite rock or a layer about one-fourth as thick as the zone of altered serpentine. A dike of albitite, six inches wide would have the reaction zones on each side twelve inches wide. The pegmatite assumed above is an albite-rich, quartz-poor, pegmatite. If the pegmatite were richer in albite it must contain less quartz and would approach the albitite itself in composition. If the pegmatite were richer in potash it might contain more quartz (up to 25 per cent. quartz for a pure orthoclase rock) but such a pegmatite would supply a much smaller layer of albitite.

It is not possible to account in this way for the great bodies of albitite—many feet across—bordered by reaction zones only a foot or so across.

Taking the dike in Brinton's Quarry (see Fig. 4), which has a central part of "normal pegmatite" and a border of albitite, and calculating the material required to be added to the reaction zone and that taken from the pegmatite we get the following results:

TABLE III.

MATERIAL IN GRAMS THAT MUST HAVE BEEN REMOVED FROM A SQUARE CENTIMETER CROSS SECTION OF THE CENTRAL PEGMATITE TO YIELD THE BORDER ZONES OF THE PEGMATITE AT BRINTON'S QUARRY.

	SiO_2.	K_2O.	Al_2O_3.
Albitite—10 cm.	44.5	4.6	5.0
Albite-orthoclase rock 20 cm.	26.0		
Material taken from pegmatite	70.5	4.6	5.0
Material added to reaction zone as previously calculated	21.5	3.9	4.0

The reaction zone is about 30 cm. wide and has about the composition used in the preceding calculation. The central or "original" part of the pegmatite has about equal amounts of quartz, orthoclase, and albite. The border zone of the pegmatite is

about 10 cm. wide and is nearly pure albitite. Between this and the pegmatite are about 20 cm. of rock made up of about equal amounts of orthoclase and albite with a little quartz. The material that must have been removed from the pegmatite to give these zones, assuming that the maximum amount of reaction zone possible was formed, is shown in Table III.

Hence even for this dike where the data are roughly quantitative and which is considered by Gordon to give the most conclusive evidence of desilication, the material added to the altered serpentine zone is very different from that taken from the pegmatite. The border zones of the pegmatite have lost somewhat more K_2O and Al_2O_3 and over 3 times as much SiO_2 as the altered serpentine has gained, and making all allowances for the crudeness of the calculation the order of magnitude of the two is certainly different, at least for the SiO_2.

For the plumasites and other corundum bearing veins the chemical relations are even less favorable for the theory of direct reaction between the pegmatite and the dunite. Taking the detailed data of Chatard (3) for the width and chemical compositions of the different zones, assuming that the chlorite was derived from biotite and considering only the major constituents, the average composition of the vein plus the "reaction zones" is: SiO_2 39 per cent., Al_2O_3 16 per cent., MgO 24 per cent., K_2O 8 per cent., H_2O 13 per cent. If we assume that all the MgO came from the dunite, the "pegmatite" must have had about the following composition: SiO_2 39 per cent., Al_2O_3 29 per cent, K_2O 14 per cent., H_2O 23 per cent. which is that of a rock made up of 23 per cent. H_2O, 63 per cent. leucite, and 14 per cent. corundum.

Using the data given by Chatard (3) for the border zone or that of Pratt and Lewis (9) for either zone, we get a similar result.

Evidently the data as to the relative widths of the different zones and their chemical composition is not sufficiently detailed to enable us to recognize small differences, but they do show the general character of the system. Clearly in the Natal deposits, in the Pennsylvania deposits described by Gordon, and those described

by Bastin, and in the North Carolina deposits, the theory that the deposits were formed through the desilication of ordinary pegmatites by their reaction with peridotites and serpentines would require the removal entirely from the system of over half the silica of the pegmatite together with much potash, and for the albitites of much alumina. The chemical evidence is therefore believed to be decidedly opposed to this theory. At least, it would require a radical revision of our ideas as to the character of pegmatite magmas and the conditions under which they crystallize.

Desilication with later Movement of the Magma.

Hall proposes some movement of the magma after partial reaction with the wall rock to account for some of the wider plumasite bodies. Such a movement might overcome the objection that there is no relation between the width of the reaction zone and that of the pegmatite but the other objections hold.

Crystallization of a Magma.

The albitite and plumasite bodies might be interpreted as crystallizations from a magma with the composition of albite or albite and corundum, and the border zones of biotite, amphibole, and talc as being due to hydrothermal contact metamorphism of the ultrabasic rocks. This is much like the explanation proposed by Pratt and Lewis (9) for the North Carolina corundum deposits and seems to me to fit the facts better than the interpretation of desilicated pegmatites. The association of albite with the corundum is what one might expect from the experiments of Morozewicz [11] who found that pure soda-aluminosilicate magmas dissolve alumina in large quantity, lime magmas in small quantity, and pure potash magmas are, under the same conditions, incapable of dissolving alumina in excess.

However, the following objections to a direct magmatic origin make it seem improbable:

[11] Morozewicz, Jozef, "Experimentelle Untersuchungen über der Bildung der Minerale im Magma," *Min. Pet. Mitt.*, XVIII., 1–90, 107–240, 1899. Also abstract, *Jour. Geol.* VIII., 300–315, 1899.

1. The invariable occurrence of the albitite and plumasite in ultrabasic rocks.

2. The zones of biotite, anthophyllite, and talc in the fractures of the shattered zones in Brinton's Quarry, where they do not seem to be closely associated with any body of albitite, are not what one would expect of this interpretation.

3. The regularity of the border zones is much greater than is common in hydrothermal contact metamorphism.

4. The layering of some of the bodies with centers of aplite, and borders of albitite or plumasite and with concentration of corundum near the borders might be interpreted as due to composite dikes or hybrid rocks.

High Temperature Hydrothermal Deposits.

The considerations stated in the preceding pages show the theory of desilicated pegmatites as stated by du Toit and Gordon to be improbable without revision, and I propose as an alternative the theory that the deposits under discussion were formed as high temperature veins and replacements, probably approaching pegmatite or hydrothermal contact metamorphic deposits in their condition of temperature and concentration. For such deposits the solutions are conceived as moving along channels and depositing, either in the channels or in the adjoining wall rock only a part of their material and at the same time taking up some material from the wall rock and carrying it away. Whether conditions were such that the solutions were of the type commonly postulated for the formation of veins, with water in large amount and definitely playing the part of a solvent for the other constituents, or whether they were so much more highly concentrated as to approach pegmatitic conditions, is uncertain. The extensive alteration, and, in some deposits, hydration of the wall rock of dunite as well as the net work of veins with the usual reaction zones but with little or no albitite, indicate a high fluidity and a large water content.

I believe that a careful consideration of all the known facts about the deposits, and in particular of the Pennsylvania deposits

with which I am personally familiar, clearly indicate a hydrothermal origin and involve fewer objections to such an origin than any other theory.

The invariable occurrence of the albitites and plumasites in ultrabasic rocks is easily explained on the theory of a hydrothermal origin, as not uncommonly a particular kind of hydrothermal deposit is confined to a single kind of wall rock. Moreover, it is probable that there is a genetic relation between the deposits and the ultrabasic rocks. In Pennsylvania, the albitites are later than the serpentinization but the serpentinization is probably deuteric and the albitites may have been formed by later solutions from the deep part of the magma.

The composition of the albitites favors rather than opposes a hydrothermal origin. Albite is a very common hydrothermal mineral[12] and it is found in association with the hydrothermal deposits from basic and ultrabasic rocks as in the glaucophane schists and the adinoles. It is also a common and abundant mineral in the hydrothermal alteration of pegmatites.[13]

Corundum is also rather common as a hydrothermal mineral as it has been formed by the contact metamorphism of shales by granodiorite[14] near Chatham, Virginia, and by replacement of limestone in Naxos, Greece.[15] A study of the literature[16] and a brief visit in the field has led me to believe that the emery deposits near Peekskill, New York, which are in schists near their contacts with norite and related rocks, are also hydrothermal contact metamorphic deposits, although Bowen[17] believes them to be due to the direct reaction between the schists and the magmas.

[12] Colony, R. J., "The Final Consolidation Phenomena in the Crystallization of Igneous Rocks," *Jour. Geol.*, 31, 169–178, 1923.

[13] Schaller, W. T., "The Genesis of Lithia Pegmatites," *Amer. Jour. Sci.*, X., 269–279, 1925. Landes, K. K., "The Paragenesis of the Granite Pegmatites of Central Maine," *Amer. Min.*, 10, 355–412, 1925. Hess, F. L., "The Natural History of the Pegmatites," *Eng. & Min. Jour.*, 120, 3–12, 1925.

[14] Watson, T. L., "A Contribution to the Geology of the Virginia Emery Deposits," Econ. Geol., XVIII., 53–76, 1923.

[15] Papavasilion, S. A., "Die Smirgellagerstatten von Naxos selbst denjenigen von Iraklia und Sekinos," *Zeit. Deut. Geol. Ges.*, 65, 1–23, 1914.

[16] Rogers, G. S., "Geology of the Cortland Series and the Emery Deposits," *An. N. Y. Acad. Sci.*, XXI., 11–86, 1911.

[17] Bowen, N. L., "The Behavior of Inclusions in Igneous Magmas," *Jour. Geol.*, XXX., 550–560, 1922.

Indeed, the presence of corundum in the schists near the contact with the ultrabasic rocks in North Carolina was interpreted by Pratt and Lewis (9) as due to contact metamorphism and it shows that solutions capable of depositing corundum originated from the ultrabasic rocks.

The association with "pegmatite" can be explained in several ways. In Brinton's Quarry the relations might be explained by assuming that the "pegmatite" was intruded first and that later solutions moved along the borders of the pegmatite, deposited the albite and altered the serpentine. In some places the aplite bodies might be interpreted as later intrusions.

One section shown by Hall (8, p. 105) has the central plumasite, rich in corundum, bordered on both sides by vermiculite and with quartz feldspar pegmatite separating the vermiculite from the enstatite-pyroxenite and if, as seems reasonably certain, the vermiculite was formed only where the plumasite intruded ultrabasic rock, then the pegmatite must be later than the plumasite and was intruded between the vermiculite and the ultrabasic rock.

However, for the Brinton's Quarry dike, I believe the quartz-microline-albite dike to be of hydrothermal origin as well as the albitite. Its texture is near that of an aplite but the grains are more irregular and ragged. It is almost identical in texture and composition with some material collected in the Eagle Mountains, California, from a hydrothermal contact metamorphic replacement of limestone. This rock, for several inches next the channel along which the solutions moved, is a dark green serpentine, probably derived from olivine or some other contact metamorphic mineral. Beyond that and rather sharply separated from it, is a zone an inch or less wide, made up chiefly of tremolite, and beyond the tremolite and sharply separated from it, is a mass of quartz-feldspar rock.

The inclusion of nearly pure quartz rock with a border rich in albite in the Brinton's Quarry quartz-feldspar rock also favors a hydrothermal origin and indicates that the first material deposited by the solutions was nearly pure quartz. The banding of the vein with quartz-feldspar rock in the center, orthoclase albite rock

next, and pure albite at the border, resembles the banding in many vein deposits.

Near Washington, D. C., the pre-Cambrian schists and gneisses are cut by many veins of nearly pure, coarsely crystalline quartz, that have narrow border zones of quartz-feldspar rock. These border zones are as much like pegmatite as is the quartz-feldspar rock of Brinton's Quarry.

The reaction zones of the serpentine, with biotite next the albitite, anthophyllite or actinolite beyond that, and talc next the serpentine, is an arrangement and mineral assemblage that strongly suggests hydrothermal action. The fact that a part of the talc, at least, is derived from the amphibole shows that at least some of the products are hydrothermal.

The lack of correspondence in width of the albitite and of the bordering reaction zone, and the common occurrence of fracture zones with the usual layers of mica, amphibole, and talc, and but little feldspar, are most easily explained by a hydrothermal origin. The size of the albitite seems to depend on the size of the open space available for filling. That the border zones around the albitites and the plumasites are nearly similar, and that they differ little in serpentine, dunite, or pyroxenite, offers no difficulties to a hydrothermal origin.

The above considerations make it seem highly probable that the deposits were of hydrothermal origin.

The character of the deposits and the associated zone of alteration indicate that the solutions were rich in alumina, rather rich in alkalies, especially soda, relatively poor in silica, and poor in magnesia, lime, iron and heavy metals. In stating that the solutions were rich in any constituent one can only mean, that they are saturated with that constituent, under existing conditions.

The invariable association of the veins with peridotite and related rocks and their common occurrence along the peridotite contacts would indicate that the solutions emanated from the ultrabasic or a related deep-seated magma. The extreme poverty of the magma in alumina and soda, the chief constituents of the vein zone, is no bar to this origin, since a common type of contact

metamorphism by peridotites is the development of schists rich in albite, soda mica, and soda amphiboles. Moreover, magmas commonly give rise to contact metamorphic zones composed of constituents in which they are low. For instance, granites and granodiorites low in magnesia and iron form large contact deposits that are rich in magnesia and iron.

The character of the wall rock might determine the kind of deposit to be formed, as it does in many vein and replacement deposits. The extensive and characteristic alteration of the wall rock shows that there was extensive interaction between it and the solutions; alumina is the characteristic constituent of the veins and is the most conspicuous addition to the wall rock.

The hydrothermal theory not only accounts for all the phenomena explained by the desilication of pegmatites, with the exception of the observations that dikes remain pegmatitic in granulite, and are changed to plumasite in serpentine, but it meets the objections raised by the desilication theory. Moreover, it accounts for the corundum that occurs in North Carolina in the schists and gneisses along and near the contacts of the ultrabasic rocks, by considering that it was deposited in the wall rock by the same aluminous solutions that deposited the corundum in the veins.

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BIBLIOGRAPHY.

The following list includes chiefly the more recent papers dealing with plumasite and albitite bodies but also includes some of the older papers that contain detailed descriptions of deposits, or that otherwise aid in their interpretation. For a detailed bibliography see Cobb (4).

1. BARLOW, A. E. Corundum, its Occurrence, Distribution, and Uses. Can. Geol. Survey, Mem. 57, 1915.
2. BOWEN, N. L. The Behavior of Inclusions in Igneous Rocks. Jour. Geol., XXX., 550–558, 1922.
3. CHATARD, T. M. The Gneiss Dunite Contacts of Corundum Hill, North Carolina, in Relation to the Origin of Corundum. U. S. Geol. Surv. Bull. 42, 57–59, 1887.

4. Cobb, Margaret, C. The origin of Corundum Associated with Dunite in Western North Carolina. Dissertation, Bryn Mawr College, 1924.
5. Du Toit, A. L. Plumasite (corundum-aplite) and Titaniferous Magnetite Rocks from Natal. Trans. Geol. Soc. So. Africa, Trans., 21, 53–73, 1918.
6. Fersman, A. Ueber die magmatischen Pegmatites des Urals. Comp. Rend. de l'Acad. des Sc. de Russia, 69–72, 1925.
Fersman, A. Ueber die Genesis der Smaragdgruben im Ural. Comp. Rend. d'Acad. des Sc. de Russia, p. 57–60, 1925.
7. Gordon, S. G. Desilicated Granitic Pegmatites. Proc. Acad. Nat. Sc. Philadelphia, Part 1, 169–192, 1921.
8. Hall, A. L. Corundum in Northern and Eastern Transvaal, Union of South Africa Geol. Surv. Mem. 15, 1920.
9. Pratt, J. H. and Lewis, J. V. Corundum and the Peridotites of Western North Carolina. N. C. Geol. Surv. Vol. 1, 1905.
10. Saxen, M. Ueber die Petrologie des Otravaaragebietes im Ostlichen Finnland. Bull. Com. Geol. Finlande, 65, 28–30, 1923.

SILVER MINERALIZATION AT BEAVERDELL, B. C.

H. E. McKINSTRY.

THE limited vertical range of some rich silver deposits has in many cases led to a confusion between primary zoning and secondary enrichment. The two processes are not as easily distinguished as in the case of copper deposits and the traditional criteria need to be applied with caution. It is believed that field and laboratory study going hand-in-hand and applied to a large number of examples will eventually afford a more reliable basis of distinction.

The veins of Beaverdell are of particular interest since they present an almost ideal illustration of ore deposits related to an igneous intrusion where both the depth of deposition and depth of the intrusion are definitely known.

Beaverdell is in the Boundary District of Southern British Columbia between Okanagan and Kootenay Lakes. The mines are located on Wallace Mountain which overlooks the valley of the Westkettle River and the town of Beaverdell on the Kettle Valley Railway.

The writer, whose field observations were limited to the Sally and Rob Roy groups, is indebted to Mr. Henry Lee, now of the Bell Mine, for much information and kind assistance. To Professor L. C. Graton thanks are due for valuable advice and discussion.

GENERAL GEOLOGY.

The geology of the district is described by Reinecke.[1] The relatively flat-lying Mesozoic sediments of the Wallace group (metamorphosed lavas and tuffs overlying limestone and hornfels) occupy the uplands. They are intruded first by the quartz diorite of the Westkettle Batholith (Jurassic) and this in turn

[1] "Ore Deposits of the Beaverdell Map-Area," Canada Geol. Survey, Mem. 79, No. 65 Geol. Series, 1915.

by the quartz-monzonite of the Beaverdell Batholith (Eocene) (which is really little more than a stock).

Westkettle Quartz Diorite.—The batholith occupies an area of at least 200 square miles though exposed only in the valleys which cut through the overlying Wallace group. The rock is granodiorite characterized by low iron, high calcium, and moderate content in alkalies. The minerals are orthoclase and labradorite with quartz, biotite, and hornblende. It is correlated by Reinecke with the Okanagan composite batholith.

Beaverdell Quartz Monzonite.—The stock as exposed in the bottom of the valley is about two miles in diameter. The rock is more siliceous than the quartz diorite but resembles it in containing low iron, high ratio of calcium to magnesium, and unit ratio of sodium to potassium. The rock is characterized by large pink feldspar phenocrysts, usually Carlsbad twins, which are microperthite composed of anorthoclase or soda-orthoclase intergrown with albite in the proportions of five to one. Quartz composes about 14 per cent. of the rock, biotite about 5 per cent. with smaller amounts of hornblende and titanite.

Summary.—The similarity in composition of the two intrusives suggests that they are differentiates from the same magma, the later differentiate being the more siliceous.

Thus a small stock intrudes a batholith which has already intruded earlier sediments and volcanics. The veins occur about the stock but in the batholith and where they pass upward into the Wallace formation they become non-productive.

ORE DEPOSITS.

Veins.—The veins strike east and west, and most of them dip southward, although a few are vertical or dip northerly. They vary in width from a few inches to six or eight feet, though the individual ore-bearing streaks are rarely more than a foot or so in width. In places the vein or "shear-zone" consists of a number of parallel ore streaks. The veinlets forming the lodes undergo intricate branching and in places almost form a breccia of the country rock. Large vugs and coarse comb-structure occur, but are rare. Tiny vugs in the quartz are common.

The veins are offset by numerous faults most of which, however, are not of more than a few feet displacement; the largest reach 100 feet or more. The most conspicuous series has a general north-south strike and a flat westerly dip. Usually the hanging-wall has been offset to the south and the rare northward dipping veins have been offset northward. The gangue is mainly quartz but this is minor in amount. The vein filling consists of pyrite with some arsenopyrite, sphalerite, galena, tetrahedrite, and pyrargyrite. The proportion of the minerals varies. In some veins pyrite predominates, in others, sphalerite and in still others galena. Usually all the other minerals mentioned are present. Ruby silver tends to accompany pyrite, and tetrahedrite accompanies galena.

An entirely later type of mineralization consists of veins carrying calcite, argentite, and native silver. They are later than the earliest faulting, as the faults themselves show mineralization of this type and bear delicate unshattered calcite crystals. In the adjoining Bell mine, veins of this type yield native silver in association with green fluorite.

Ore of the same type as that of the Sally has been found on and adjoining the Wellington Claim at an elevation as low as 3,400 feet and nearer the quartz monzonite intrusive. Ore from other mines near the valley bottom, which is at 2,500 ft. elevation, consists of coarse-grained sphalerite and galena with decidedly lower silver content and higher gold.

Laterally, the veins have been shown to be quite persistent; the ore shoots are interrupted by faults rather than by pinching of the vein. The present indications are that some of the veins are traceable for over 1,000 feet and exploration is far from complete. Vertically, the upper limit of ore-bearing ground is determined by the overlying Wallace Group which forms the roof of the quartz diorite stock. This contact is nearly flat in the neighborhood of the Bounty and Tiger Claims and at an elevation of about 4,500 feet.

Order of Deposition.—The mineralization is of three distinct generations, the first two being closely connected.

Veinlets of the first generation net the wall-rock and contain quartz in rude comb-structure, along with some pyrite and coarse dark sphalerite. Arsenopyrite in subhedral needles replaces the wall-rock and occurs sparingly within the veins. Veinlets of quartz, some of which is euhedral also cut the sphalerite, and pyrite grains adjoining the sphalerite, and also outline the older quartz crystals. Angular blocks of sphalerite are outlined by an almost brecciating mass of quartz-pyrite stringers. Along the centers of these stringers, irregular chalcopyrite grains are common. Surrounding crystals of the quartz of this generation and in places replacing the quartz crystals, is galena. The same mineral partially, and in places completely, replaces euhedral crystals of quartz of the first generation inside the pyrite rims. It corrodes and veins the older sphalerite. This galena is replaced in sea-and-island texture by tetrahedrite. Pyrargyrite has strongly attacked tetrahedrite, and particularly, galena. The replacement is of the sea-and-island type; the ruby silver does not follow the cleavage cracks of the galena. Its preference for this mineral is strong and it even seeks out veinlets of it in the sphalerite.

In places there are veins of a still later quartz that cuts all of the above minerals. It may be connected with the third or fault-vein generation. Finally, all of the minerals are cut by veinlets of calcite which may also be of the fault generation.

The third generation is found lining slickensided fault-veins transverse to the veins of the main series. Open vugs show a lining first of drusy quartz. Upon this are calcite crystals of at least two different ages and habits. The first appear to be scalenohedrons up to two mm. length, but in reality are piles of rhombohedrons. The subparallel grouping and re-entrant angles suggest that they have been etched. Later than these crystals, and upon them, are flat rhombohedrons of calcite—"butterfly calcite." Upon these crystals are tiny crystals of chalcopyrite. Larger chalcopyrite crystals are deposited upon pyrite. Intercrystallized with the calcite but resting, in some cases, on larger chalcopyrite crystals are flat triangularly striated crystals of

polybasite.[2] Upon the polybasite are rounded argentite crystals. Specimens from the Bell mine show wires of native silver, some of them considerably over a centimeter in length, apparently growing on the argentite, which is in places pitted and is partly coated by native silver. Octahedral crystals of green fluorite are associated with the argentite. Within the clear fluorite, rounded argentite crystals may be seen, some of them with plates of native silver attached to them. Other argentite crystals rest upon and outside of the fluorite. It is possible that the argentite and silver developed within the fluorite by replacement, but it would seem more likely that the fluorite grew and enclosed them.

In polished sections, veinlets of native silver and polybasite may be seen to cut across pyrite and the other sulphides without appearing to replace them.[3]

It appears that the order of mineralization in the fault veins is: (1) quartz, (2) calcite, (3) calcite and fluorite. Perhaps overlapping with (3) but in part following it are (4) pyrite, chalcopyrite and polybasite, (5) argentite, (6) native silver.

Summary of Mineral Sequence.—First Generation: quartz, pyrite, and arsenopyrite; sphalerite, galena (?).

Second Generation: Quartz and pyrite, galena, tetrahedrite, pyrargyrite. Exact position of chalcopyrite unknown.

Third Generation: Quartz, calcite and fluorite; pyrite; chalcopyrite and polybasite; argentite; native silver.

Primary and Secondary Minerals.—All of the minerals up to and including the galena and tetrahedrite of the second generation, are unquestionably primary. The latter two are such usual hypogene minerals that there is no reason here to consider them any exceptions. The ruby silver requires discussion. So far as observed by the writer it is restricted to the quartz veins of the second generation and is rarely if ever found in the fault veins. It is not associated with calcite or with argentite. Its intimate

[2] This mineral gave tests for silver and antimony, but no arsenic.

[3] Since the writer's visit he has been advised by Mr. Lee that fault veins in the Bell mine have been found carrying pyrite and galena. Whether they are contemporeaneous with the mineralized fault veins of the Sally group cannot, of course, be stated.

association with galena and tetrahedrite and its replacement of them in island texture, failing to follow cleavages and fractures, while not a rigorous proof, would strongly suggest that it is closely associated with these minerals in time and that there was no intervening period during which even minor fractures might have formed.

The fault veins are unquestionably later than the main mineralization, since the minerals are on slickensided surfaces of the faults which offset the older veins. The native silver may well be secondary and a replacement of the easily altered argentite. The deposition certainly took place from alkaline waters that were capable of depositing pyrite, quartz, and chalcopyrite, without forming chalcocite or covellite. The presence of well-crystallized barite and fluorite is strongly suggestive of hypogene processes, though both minerals have been reported as being deposited from supergene solutions at other localities. The sulphides deposited as well-formed crystals in vugs and not as replacements of preëxisting minerals. A fault vein in the Bell mine carries galena. On the whole the weight of evidence strongly favors a hypogene origin for all of the minerals up to the native silver.

SUPERGENE PROCESSES.

Outcrops.—The veins do not outcrop prominently. The small amount of quartz gangue unaccompanied by strong silicification of the wall-rock presents little resistance to erosion. The sulphides themselves, weather to a soft crumbling mass. The surrounding diorite tends to slough in and conceal the outcrop.

Shallow workings show at the surface only a streak of limonitic clay and below it a zone of porous iron-stained decomposed diorite and quartz. Often within ten feet of the surface sulphides are encountered, the sphalerite showing stains of covellite and at depths of thirty feet high-grade ore has been mined. The water in surface workings stands at depths of less than fifty feet below the surface. Oxidation in the workings below the fifty foot level is slight. The high water-table on the flat top of Wallace Mountain seems to have prevented deep oxidation.

Native silver occurs in dendritic leaves along fracture zones in the ore, accompanied by greenish chloritic material and gouge. This, as well as the native silver in the fault veins, is probably supergene, but if the writer's interpretation of the origin of the vein minerals is correct, secondary enrichment has not been of great importance.

WALL ROCK ALTERATION.

The alteration does not extend far from the veins and consists of sericitization with a little silicification. Plagioclase is replaced by sericite; microcline, in part by calcite; biotite, by muscovite, calcite and titanite; other ferromagnesian minerals, by chlorite and calcite. A more intense phase consists of deposition by replacement of granular quartz and arsenopyrite along with pyrite, sphalerite, and galena. This last type of alteration is confined to fairly well-defined veinlets. Potash was the chief material introduced.

ORIGIN OF THE ORE.

The obvious source of the ore appears to be the Beaverdell batholith. During its intrusion and cooling, fractures probably formed in the intruded Westkettle batholith, and disappeared in the overlying Wallace formation. Solutions carrying silica, iron, zinc, lead, copper, silver, sulphur, arsenic, antimony and potash entered the fractures. After the crystallization of the minerals from these solutions, faulting took place, and solutions, possibly still ascending along the original fissures and perhaps of somewhat changed composition, were now able to deposit chalcopyrite and pyrite, calcite, barite, fluorite, polybasite and argentite.

The Beaverdell batholith according to Reinecke [4] was intruded in Eocene time and the faults which cut the veins were not later than the end of the Oligocene, so that the ores must have been deposited during the Eocene or Oligocene, The same author places the depth of formation at not over 2,000 feet, while the ores of Carmi in the valley bottom formed 1,000 feet deeper. The ores of the mines in the valley consist of pyrite, sphalerite, galena, and

[4] *Op. cit.*

chalcopyrite, all coarse textured and with their chief values in base-metals. Tetrahedrite is said to be lacking, silver content is lower and gold content higher. Molybdenite and ankerite occur sparingly. These ores are clearly of a higher temperature type than those of Wallace Mountain. In the Wellington Mine, 600 feet lower than the Sally, according to Mr. Lee, shipments of ore carrying 300 oz. of silver have been made. There, tetrahedrite is still present, but visible ruby silver is rare or absent. There seems to have been a steep thermal gradient; ore of the mesothermal zone (followed by later epithermal mineralization) formed within 2,000 feet of the surface, ruby silver disappears 600 feet lower, and tetrahedrite at less than 400 feet below this. This of course is a generalization and may be subject to local variations, but it would appear that the proximity of the Beaverdell intrusion to the veins and to the surface might account for the rapid gradation in conditions.

DISCUSSION.

Within such a limited vertical range the tendency of the normal rock-temperature gradient to produce zoning must have been slight. Because of the long time that would be required for a batholith to warm its roof by heat conduction alone, we are forced to conclude that the vein solutions themselves have been the chief agents in heating the vein-walls. On account of the nearness to the intrusion, the speed and volume of the ascending solutions would exert a great influence on the temperature, and a cessation and renewal of flow would register itself in a repetition of generations of mineralizations. The three generations at Beaverdell are in line with the result that would be expected under such conditions.

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TECHNIQUE OF THE INVESTIGATION OF IRON ORES.

FRELEIGH F. OSBORNE

THE writer has recently been engaged in a study of the nature and genesis of certain titaniferous iron ore deposits in New York, Quebec, and Ontario.[1] The results of this study form the basis of a paper now in the course of publication in this journal. A part of the investigation involved a mineralographic study of the ores, and it was found that the existing methods of identification of the iron minerals under the microscope were not wholly satisfactory. Consequently it became necessary to evolve certain technique for their identification and study. As this technique is not inserted in the paper mentioned, a few notes regarding it are given here in advance, in the hope that it may prove useful to others in the identification of magnetite, hematite, ilmenite, and spinel or other minerals listed as "negative to all reagents."

Etching.—In the examination of the polished surfaces of the titaniferous ores under the microscope etching proved most helpful, not only in mineral identification, but also in revealing the structures of the minerals. Drops of reagent applied to the surface of the minerals with a platinum wire or pipette in the usual manner did not produce the desired etching. In the first place, the drops evaporated too rapidly and in the second, if large drops were applied the etching produced was uneven. The only effective etching was secured by placing the mineral surface in contact with a considerable volume of reagent. This has commonly been done by immersing the specimen in the reagent. But this involves the drawback of having to re-polish the surface after each test; also specimens cemented in fibre or metal holders with

[1] The study was carried on as an Emmons Memorial Fellow and the results were submitted as a dissertation for the Doctor of Philosophy degree at Yale University.

wax can not be treated in this way because the holder and wax are attacked, especially by warm acids.

An etching technique was devised so that 1 c.c., or less, of the reagent could be placed in contact with a small area of the surface. By this method it is possible to make several long etching tests on the same specimen and still have unetched surface left for observation. Cylinders from 6 to 15 mm. long sawed from 9 mm. pyrex tubing are ground to flatness on a lap and carefully smoothed with the finest carborundum. The cylinders are placed in contact with the surface and filled with the reagent, which is left until the etching reaches the desired stage. The cylinders may be placed on the polished surface without cement if not more than .3 to .4 c.c. of the liquid is used, or they may be cemented with collodion, vaseline, or paraffin. The collodion has the advantage that it may be readily removed from the surface on completion of the etching, but it can be used only with weak acids. Vaseline may be used with hot reagents and paraffin with HF. Both paraffin and vaseline are inclined to adhere to the surface and to fill crevices, but they may later be removed with benzol, alcohol, or ether.

The part of the surface to be etched is centered under the objective; the end of the cylinder is placed in contact with the conical metal mount of the objective and the microscope is racked down until the lower end of the cylinder, which has been coated with cement, is in contact with the surface. The conical lense mount allows almost perfect centering. When the rings are in place they may be filled with etching reagent. With a short cylinder the progress of the etching may be watched through the microscope but if strong acids or HF are used it is advisable to protect the objective by a cover glass held over the lense by cedar oil. The progress of the etching may be checked at any time by withdrawing the reagent with a pipette, rinsing with water and drying with a stream of air or a blotter, without removing the cylinder. It may be continued by adding more reagent. An advantage of the method is that a number of the cylinders may be cemented to the surface and filled with different reagents so rates of etching of different reagents may be compared.

A further refinement of the method is in the use of a heating element. The writer used a coil of fine platinum wire with a five-volt current delivered by the resistance box of a Leitz "Mignon" lamp. The coil is immersed in the liquid until the desired temperature is attained. The writer's coil was a little short so that the rate of heating was too slow, but a larger coil would remedy this difficulty. It should be feasible to wind the outside of the cylinders with resistance wire and heat them by that means although this was not attempted. The cylinders are further helpful in electrolytic etching using two electrodes, both filled with reagent, or one with mercury and one with reagent. If the mineral is a poor conductor both electrodes may be inserted in the same cylinder. Ilmenite, ordinarily resistant to common reagents, etches readily under these conditions with HCl.

Cylinders under 9 mm. diameter are not advisable. Capillarity causes a distortion of the surface of the reagent so that it acts as a lens and thereby prevents observation under the microscope during etching. A further difficulty is that with small cylinders it is difficult to get the reagent to the bottom of the tube.

Some ores, for example those containing carbonates, are dissolved by the etching reagents and the liquid may escape beneath the cylinder. In this case it is necessary to dissolve the soluble material and impregnate the specimen with paraffin before cementing the cylinder.

In the experience of the writer more consistent results are obtained by using the total immersion method than the drop method, and the cylinders give results fully as satisfactory as those obtained by the immersion method without the disadvantage of destroying the polish of the entire surface. It was found that the results of etching are better if, after polishing, the surface is brushed with soap and water, dried and sponged with alcohol or ether, then rubbed on a clean dry cloth. The method is also of advantage where a critical study of the etching behaviour of minerals is made; for example, by the use of the cylinders, spots that have been etched by the same acids for different lengths of time

or different reagents may be compared. The writer found that the material called hematite varies considerably in etching behaviour. The hematite that gives the bright red streak is almost unaffected by hot saturated KOH solution, but hematite that yields a red streak with a tinge of brown is quite readily etched. There is also a difference in the susceptibility to etching with HCl and HF. The comparisons are much more readily made if the cylinders are used than if whole surface is etched, besides, there is a considerable saving in time if several tests can be made on one surface without re-polishing.

Polarized reflected light.—The use of polarized reflected light does not appear to have been used as extensively in mineralographic study as warranted by the results. It was found to yield information of value in the study of the iron ores. The instrument used in this study was a Leitz Ore Microscope MOP model, shown in Fig. 1. This model is equipped with a polarizer that

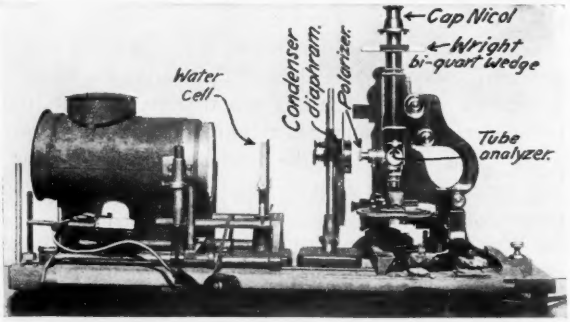


FIG. 1. Microscope equipped for observation with polarized reflected light, showing the position of the nicols and the method of illumination employed.

fits over the opaque illuminator and a tube analyzer. As supplementary equipment a Bausch and Lomb Wright bi-quartz wedge with a cap nicol were used. Adequate illumination for use under crossed nicols was a problem that gave considerable dif-

ficulty. A clockwork driven arc lamp was found to give too many color bands, so an old projecting lantern illuminated by a 500 watt Mazda projection lamp was made to serve. The projecting lenses were removed so that only the lamp housing and condensing lenses were left. Using a water cell to cut out the heat, this provided efficient and uniform illumination. For photography a "Tungsarc" lamp gave a concentrated white light.

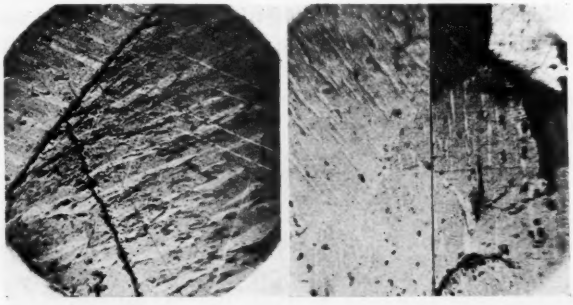
Methods of use of polarized light have been suggested by several authors, but it is only comparatively recently that the methods have been simplified [2] and the apparatus improved so that they are readily applicable in ordinary study. In general two methods are in use; in one a polarizer and analyzer are employed, in the other a Wright bi-quartz wedge is used. In the first method either a tube analyzer or a cap nicol may be used. The tube analyzer is preferable because it gives a larger and clearer field. The analyzer is placed with its vibration direction fore and aft, then the polarizer is rotated until it gives a position of maximum darkness with an isotropic substance such as magnetite or a mirror on the stage. The amount of light reaching the eye is not great, but it may be somewhat increased by slightly rotating the upper nicol. This method is useful in detecting anisotropism, and for detecting grain boundaries and twinning in anisotropic minerals as shown by Fig. 2*A*. This method has the disadvantage of not being extremely sensitive, and it gives no quantitative idea of the amount of anisotropism.

The Wright bi-quartz wedge [3] furnishes a means of detecting slight anisotropism. The vibration direction of the polarizer is made parallel to the plane of the prism. The wedge is set so that its long direction is fore and aft, that is at right angles to vibration direction of the light after it is reflected from an isotropic

[2] Wright, F. E., "Polarized Light in the Study of Ores and Metals," *Am. Philos. Soc. Proc.*, 58, 401–447, 1919. Schneiderhöhn, H., "Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen und Aufbereitungsprodukten besonders in auffallenden Licht," pp. 136–146, Berlin, 1922. Sampson, Edward, "Note on the Determination of Anisotropism in Metallic Minerals," Econ. Geol., pp. 775–777, 1923. Orcel, M. J., "Les methodes d'examen microscopique des minerals metalliques," *Bull. de la Soc. Fran. de Min.*, Tome 48, pp. 272–358, 1925.

[3] Wright, F. E., *op. cit.*

surface. An accurately mounted isotropic surface is placed on the stage and the cap nicol is adjusted until the two halves of the wedge show a uniformly dark color, which with a white mineral is a blue-gray. If, now, an anisotropic mineral is placed on the stage, during a complete rotation there will be four positions where the halves of the wedge are uniformly illuminated and four positions in which a maximum color difference of the halves of the wedge is seen. In the position of maximum color difference the rotation of the cap nicol necessary to make the halves of the wedge



A B

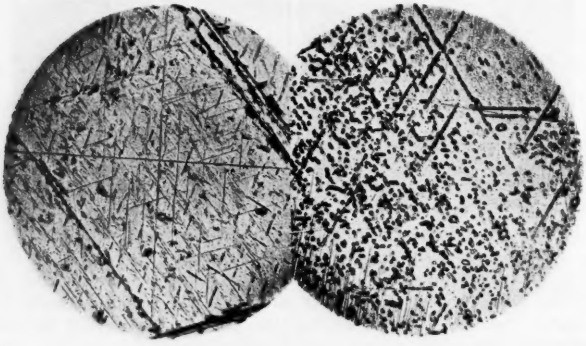
FIG. 2*A*. Ilmenite (dark) hematite (light) intergrowth showing the twinning lamellæ cutting across both minerals. The hematite lamellæ are parallel to the base. Polished surface with polarized light using the tube analyzer. ×48.

FIG. 2*B*. Ilmenite hematite intergrowth using the Wright bi-quartz wedge. The dark line is the junction of the halves of the wedge. Note the difference in color in the lamellae that cross the junction line. Lamellæ parallel to the wedge show no difference in illumination. ×64.

evenly illuminated is a measure of the anisotropism of that section. See Fig. 2*B*. For ilmenite and hematite the maximum value is about 1¼ degrees; that is, a section may show any amount of anisotropism between zero and 1¼ degrees, depending on its crystallographic orientation and its orientation on the stage of the microscope. Besides its use in determining anisotropism,

this method is also useful in determing the crystallographic orientation of some grains. It was found that tablets of ilmenite in magnetite are basal sections, and that the small lenses of hematite in ilmenite (see Fig. 2*A*) are parallel to the base. It is further useful in distinguishing ilmenite from spinel in etched surfaces of magnetite. The spinel is isotropic so that it does not show any change in color where it crosses the boundary between the halves of the wedge.

Applications.—The differentiation between magnetite, ilmenite, hematite, and spinel and the determination of some of their relationships illustrate the use of some of the methods outlined above. On a polished and unetched surface the hematite is plainly visible



A B

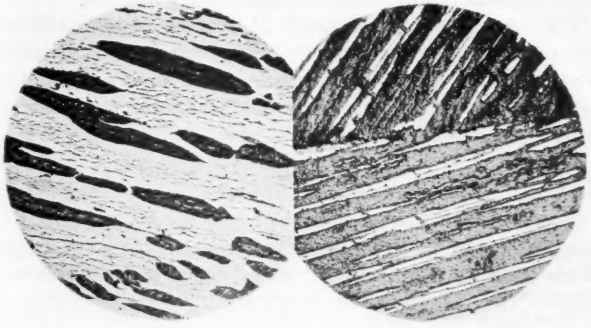
FIG. 3*A*. Slightly etched surface of non-titaniferous magnetite showing spinel as short heavy lines nearly at right angles and octahedral parting as fine sharp lines. The central lines are crosshairs. × 53.

FIG. 3*B*. Artificially polished octahedral section of magnetite showing development of triangular etching pits. × 53.

against magnetite or ilmenite on account of its white color and superior hardness. The ilmenite is only slightly more brown than the magnetite but it is anisotropic under crossed nicols and may show a color change on rotation with one nicol. It com-

monly shows a twinning parallel to the first order pyramid $(10\bar{1}1)$,[4] as shown in Fig. 2*A*. This twinning even with only one nicol is occasionally evident as bands of creamy-white color in a brownish-white background, or *vice versa*. Spinel lamellae are common in magnetite. They are plainly visible on an unetched surface as dots and dashes arranged parallel to the trace of the cube. See Fig. 3*A*. However, on the etched surface they have been confused with ilmenite lamellae and indeed they are difficult to differentiate. If a spinel lamella is in contact with one of ilmenite there is no difficulty but where either occurs alone it is necessary to use polarized light as previously described.

Magnetite is etched by HCl, HF, H_2SO_4, and acid $KMnO_4$. The rapidity of etching and the resulting pattern varies with the orientation of the grains. In some cases there are well developed triangular pits, as shown in Fig. 3*B*, formed on the octa-



A B

FIG. 4*A*. Ilmenite-hematite intergrowth showing hematite (dark) etched with HCl and ilmenite (light) untouched. Note the secondary lamellæ of ilmenite in hematite and hematite in ilmenite. $\times 45$.

FIG. 4*B*. The same etched with HF showing the ilmenite (dark) dissolved. $\times 45$.

[4] Mugge, O., Rosenbusch-Wulfing, Mikr. Phys., etc., Spez, Teil. p. 161, 1927.

hedral face;[5] however, where octahedral parting is strongly developed it etches out instead.

Ilmenite is not visibly affected by any of the above reagents except HF. Hematite is unaffected by HF except after long treatment, but its behavior toward HCl is variable. The hematite intergrown with the ilmenite is etched with HCl but less rapidly than magnetite. Other hematite shows no reaction to HCl. Furthermore, the hematite of the intergrowths is ferromagnetic. In the opinion of the writer the anomalous properties of the hematite of the intergrowths may be due to the solid solution of magnetite in hematite although the existence of such solid solution is still questioned.[6] The hematite of the intergrowths on direct comparison seems slightly more brownish or creamy than ordinary specular hematite. Polarized light shows however that it has the same crystallographic orientation as the ilmenite, which acts as the host. The spinel is not visibly affected by any of the reagents in the time used in the etching.

The writer is indebted to the S. F. Emmons Memorial Fellowship for funds to carry on the study of the problem of which this is a part, and to Prof. Alan M. Bateman for suggestions and criticism during the preparation of the manuscript of which this paper is a brief extract.

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[5] Honess, A. P., "The Nature, Origin, and Interpretation of the Etch Figures of Crystals," p. 22, Wiley, 1927. Becke, F., "Aetzversuche an Mineralen der Magnetitgruppe," *Min. pet. Mitt.*, 7, pp. 203–216, 1885.

[6] Ruer, R., and Nakamota, M., "Uber Eisen und Kupferoxyde," *Rec. de trav. Chim. de Pays-Bas*, 42, pp. 675–682, 1923. Sosman, R. B., "The Common Earths," *Ann. Surv. of Am. Chem.*, Vol. 2, pp. 123–129.

EDITORIAL

WHAT IS THE JOB OF THE ECONOMIC GEOLOGIST?

F. L. RANSOME, in his sound and instructive presidential address to the Society of Economic Geologists,[1] reminds us that the core of economic geology is the science of geology itself. "In more or less intimate affiliation as many of us are with the development and exploitation of mineral resources, there is real danger that we drift away from the obligation to contribute to that branch of science which we are applying to utilitarian ends. . . . Unless we remember that we are primarily scientific men we are likely to become content with the accomplishment of the particular job in hand and to lose sight of, or become apathetic towards, the broader consideration of our relation to scientific progress."

I heartily endorse this view. Many economic geologists who are but poor scientists succeed commercially, but this success is one of business and not of science. Such men are likely to have qualities or opportunities which would bring business success even without the science.

It does not follow that the economic geologist should withdraw into a shell of pure science. Peripheral contacts are to be looked after. Commercial and utilitarian aspects of the subject are given attention as a matter of course, but there are others which yield no immediate reward, which do not often enter our routine work, and which are too often ignored, as in President Ransome's address. I refer to the broader political and public contacts of economic geology, particularly those relating to mineral resources. The geologist is in a favored position really to understand mineral resources, to know the distribution and limitations of reserves and the most probable lines of future exploration and development. Mineral resources are playing an increasingly large part

[1] Ransome, F. L., "Directions of Progress in Economic Geology," ECON. GEOL., vol. 23, pp. 119–131, 1928.

in public affairs. Governments are giving more attention to them, and even taking a certain measure of control. There is a widening understanding of their importance as a basis of national prosperity. Public policies relating to them are being formulated. Taxation is taking special forms for natural resources. International political problems are arising from the growing recognition of the disparity in nature's distribution of resources among the nations. The subject of conservation is rapidly coming out of the academic field into practical affairs; never before has there been so much need of real understanding both of its underlying philosophy and of its practical aspects. The times are calling for a better understanding of mineral resources in their public relations, both in peace and war, from a world as well as national viewpoint.

I think I do not exaggerate in saying that the profession as a whole has shown a certain apathy and inertia to this inspiring call. In some quarters the attitude has been taken that this is not the geologist's job, with the result that some crucial questions affecting mineral resources have been settled without proper regard for information and perspective which the geologist only can supply. It is not necessary or desirable that the geologist should do this at the sacrifice of scientific work, any more than that he should go over completely to the commercially applied phases of his work, but as a good citizen he can go at least half way in making his information available for the public good and in aiding in the formulation of intelligent thought.

The American Institute of Mining and Metallurgical Engineers and the Mining and Metallurgical Society of America, with the coöperation of economic geologists, have contributed reports of much usefulness to governments and others primarily interested in public affairs. Other reports are in preparation. It is very reassuring to note the eagerness with which these contributions have been publicly absorbed and in some cases put to practical use. Various other organizations, such for instance as the Williamstown Institute of Politics, the Social Science Research Council, the Council on Foreign Relations, to mention only a few

of many, have invited coöperation from geologists in the study of this field. Government departments, including the War and Navy Departments, have done the same. One of the most interesting of recent developments is the enlargement of the scope of the Economics Branch of the Bureau of Mines, publishing "Mineral Resources," to cover this field from a broader geographic standpoint, and to include significant political and conservational developments affecting the mineral industry.

Notwithstanding such notable starts as these, it may be said that economic geologists as a group are just beginning the process of self-education necessary to intelligent participation in public thought on mineral resources. If the general call of public service has no appeal to some economic geologists, perhaps they will respond to a more specific call transmitted to them in another way. To an increasing extent intelligent handling of commercial problems requires understanding of world conditions and of the political and public relations of particular mineral products. It is not surprising that the geologist working in isolated fields, with more or less stable markets and standards of value, should taken public aspects of his problems for granted, but this attitude has in recent years led to some serious blunders of judgment. Many illustrations might be cited to show that he cannot go very far even with his own problem without orienting himself to the broader perspective.

In short, the primary allegiance of the economic geologist is to pure science. Of necessity he must learn something of the economic field. The additional opportunity now opens wide before him to aid in the interpretation of his field for the public welfare. Does the adjective "economic" in our title limit our field too narrowly for the future? Will the time come when it should be replaced by something broader, or even dropped?

C. K. LEITH.

DISCUSSION AND INFORMAL COMMUNICATIONS

CERTAIN BROWN IRON ORES IN ALABAMA.

Sir: In No. 1 of vol. 23, ECONOMIC GEOLOGY, George I. Adams presents an article on the occurrence and age of certain brown iron ores in Alabama and adjacent States, in which he discusses the age of deposits in four areas, viz., near Woodstock, Ala., 30 miles southwest of Birmingham; near Russellville in northwestern Alabama; west-middle Tennessee; and northeastern Alabama-northwestern Georgia. With the details of the deposits of brown iron ore in the first three of these areas I am familiar, and I would like to comment on the conclusions drawn by Doctor Adams as to their Tuscaloosa (Upper Cretaceous) age.

Doctor Adams kindly credits me with having described clearly certain of these deposits, and if that be the fact it is all that was attempted as a result of the field work to which he refers, which was done in 1906 and 1908.

Doctor Adams seems to have fallen into a misinterpretation of the sequence of events where he states on page 86 of his article that an identification by E. C. Eckel of gravel that is perhaps of Tuscaloosa age as "Lafayette" misled me into a similar conclusion as to the gravel in the Russellville district. The cited paper by Eckel was published in 1910, whereas that by me was published in 1907, and my own correlations followed the current usage of the Alabama Geological Survey. Doctor Adams seems also to have misinterpreted my classification of the deposits of brown iron ore in the Woodstock district. In this connection my description reads: "Most of the ore-bearing materials are apparently of Cretaceous age, although some are later. The ore may therefore be divided into two types: (*a*) the main ore masses, which occur with the Cretaceous clays and sands, and (*b*) the

later ore, which occurs in Tertiary loam and gravel."[1] By "ore-bearing materials" was meant the inclosing sands and clays, but it was not intended to convey the belief that the ore within the Cretaceous sands and clays was syngenetic. In fact, it appears that the term "Cretaceous ore" was avoided, but "Tertiary ore" as applied to the type (*b*) was used by me, as there was some justification for such usage geologically, as well as for the purposes of description. The variance of opinion between Eckel and me on which Doctor Adams builds some of his comments was thus more apparent than real. Twenty years ago the knowledge of the Coastal Plain deposits as well as of the physiographic history of the region was insufficient for a satisfactory solution of the questions of the origin and age of the ores. Since then students of Coastal Plain deposits have entirely changed the conception of the "Lafayette" as it was formerly understood, so that the formation name has been nearly eliminated from usage and materials formerly included in it are now largely grouped with underlying deposits; thus it comes about that the Tuscaloosa in northern Alabama is now considered to include gravels that formerly were called "Lafayette." The Coastal Plain specialists have, however, paid little attention to questions concerning the age of materials of economic value associated with the deposits, and it has remained for investigators who have opportunities to bring together the related facts, as Doctor Adams has done. There is still much need for further detailed study, particularly of the physiographic relations and paleobotanic associations of the iron ore deposits, and a more thorough knowledge of the biological and physical-chemical processes affecting the deposition of these ores would be very helpful.

One of the principal lines of evidence that Doctor Adams uses to show that the brown iron ore deposits are of Cretaceous age is their occurrence within and below gravels, sands, and clays of the Tuscaloosa formation, and it is a fact that deposits of limonite are within and below gravels and other sediments probably of Tuscaloosa age in both the Woodstock and Russellville districts,

[1] U. S. Geol. Surv. Bull. 400, p. 153.

Alabama, in the western Highland Rim area of Tennessee, and in western Kentucky. Limonite is often found cementing portions of the gravel into hard conglomeratic masses; this process could hardly have taken place while the gravels were being rapidly transported by streams. The Tuscaloosa gravels are chiefly of subangular fragments of chert derived from Mississippian rocks found in Tennessee and Alabama but they contain also minor quantities of smoothly rounded pebbles of quartzite and some that are possibly of vein quartz, the source of which is unknown. The angular edges of the chert gravel have been rounded off as if they had been washed back and forth on a beach, although they are considered by some to be continental deposits.

Merely because deposits of limonite are found within and at the base of the Tuscaloosa gravels is hardly more convincing evidence that they are of Tuscaloosa age than that the occurrence of a metalliferous vein or a replacement deposit within a certain limestone should be regarded as indicating that the metalliferous deposit is of the same age as the limestone. If it appears that these deposits can not well have been formed under the conditions that prevailed during Tuscaloosan deposition it makes the determination still more doubtful. Also, it seems entirely possible to explain the formation in post-Cretaceous time of many of the deposits of brown iron ore in the South, especially those in the western Tennessee Valley region.

Doctor Adams states that a description by me of the iron ore deposits in western Tennessee in the Manufacturers Record does not discuss their age. The reason for this omission is obvious, but in my official report [2] on these ores published before Doctor Adams' paper appeared in ECONOMIC GEOLOGY it is shown that I regard these deposits as of post-Cretaceous age, and Miser has given good evidence for a similar conclusion as to the deposits in the southern part of the same area.[3] In my discussion of the origin of these ores it was endeavored to show that the Mississip-

[2] "Brown Iron Ores of West-Middle Tennessee," U. S. Geol. Surv. Bull. 795-D, pp. 74–77, October 20, 1927.

[3] Miser, H. D., "Mineral Resources of the Waynesboro Quadrangle, Tennessee," Tenn. State Geol. Surv. Bull. 26, pp. 58–62, 1921.

pian limestones, which would naturally have been the source of a Cretaceous ore, are not an adequate source of the iron in the deposits, and there was given an outline of what is believed to be a possible solution of this phase of the question, both as to source and process of deposition.

The essential features of the process suggested are that the iron in the present deposits was derived from glauconite-bearing beds of Cretaceous age later than the Tuscaloosa that formerly overlay this region but are now present east of the Tennessee River only as isolated remnants, with possible contributions from similar beds of the Tertiary. Leaching, weathering, and erosion of the glauconite-bearing beds during the base-leveling that formed the Highland Rim Peneplain should have enabled surface waters to gather and distribute large quantities of iron salts in solution until finally they became concentrated in swamps and bogs on this peneplain. The iron may have been held in solution as a carbonate through the aid of organic acids. The peneplain probably originally contained larger areas of Tuscaloosa gravel than at present. This gravel afforded easy passageways for downward-moving solutions, which deposited iron carbonate as a cementing material within the gravel and when oxidized to limonite formed the ferruginous conglomerate that is fairly common in isolated remnants of the Tuscaloosa in Tennessee but more abundant near Russellville, Ala. The larger masses of limonite naturally formed at the base of the gravel, where precipitation was favored, physically and chemically, by contact with the less pervious limestone, and took place in the hollows on the limestone surface that were formed by solution. Such deposits are also particularly typified by the ores near Russellville, southwest of which place the Cretaceous gravel and sand may, perhaps, reach a thickness of 80 to 100 feet. With the removal of most of the Cretaceous gravel by erosion and the subsequent deep weathering of the Mississippian cherty limestone in Tennessee, conditions favored the development of the present limonite deposits through a further downward migration of the iron-bearing solutions and settling of the existing masses of limonite into the residual clay

and chert. Possibly the downward movement was retarded in places by less cherty limestone beds which have subsequently, through subsurface weathering and solution, been removed, leaving beds of fine-grained light-colored clay or "white horse" of varying thickness between the ore and the present limestone surface. Also it would seem that in the western Highland Rim area the solubility of the limestone along joint openings and the porosity of the residual chert and joints in the clay have afforded easy access for surface waters bearing iron in solution, and these waters in percolating downward have deposited iron minerals in places where conditions favored precipitation. Masses of ore thus formed in depressions and cavities, some of which probably were formed by the collapse of the roofs of caves, have been left as deposits in residual clay when the surrounding limestone has weathered away.

Knowledge of the details of the physiographic development of the Western Tennessee River Valley region is too meager to permit conclusions to be drawn with great assurance as to the influence of peneplanation on the formation of the deposits of hydrous iron oxide, and the same may also be true with regard to deposits of hydrous oxides of iron, manganese, and aluminum in residual clay in other parts of the South, or to enable definite correlations to be made between widely separated deposits, but if the deposits of brown iron ore in the Western Highland Rim of Tennessee were deposited, as suggested in the above outline, during and since the development of the Highland Rim peneplain, which according to geologic evidence was formed during the Eocene epoch, it naturally follows that the ore deposits themselves are probably in part of Tertiary age and probably in part of later age, perhaps of the Pleistocene.

Doctor Adams' paper has stimulated an interest in this question that may result in some pertinent data being gathered in the near future.

ERNEST F. BURCHARD.

UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

THE ORES OF POTOSI, BOLIVIA

Sir: Through the courtesy of Mr. G. T. Bridgman of New York and Mr. Horace Graham of Bolivia, I have just obtained production figures for Potosi for the year 1926, though the information came too late to be incorporated in the article in the last number of ECONOMIC GEOLOGY. The figures are gathered by the Fiscal Commission of Bolivia, but for several reasons they can only be considered as approximate. Naturally, the output would vary with the fluctuating price of tin. In 1921 when I visited Potosi, tin sold at about 30 cents per pound while in 1926 it had risen to more than double that amount.

The Soux properties, incorporated as the Cia. Minera de Potosi, have the largest production.

In 1926 the silver produced in the mines of Cerro de Potosi amounted to about 650,000 ounces. The approximate production of tin in the same period (metallic contents of concentrates) was about 3,500 tons. It is said that the same production was maintained in 1927. The output of the old Cerro thus still remains a factor of importance. The present value of the tin is about ten times that of the silver.

WALDEMAR LINDGREN.

REVIEWS

The Divining Rod. By Sir William Barrett, F.R.S., and Theodore Besterman. Methuen & Co., Ltd., London, 1926. Pp. xxiii, 336, 12 plates.

One suspects, after reading the volume under review and noting the almost indecent haste with which the authors drop the term *divining* in favor of *dowsing,* that only through the exigencies of a hard-headed publisher has the work come to us under the better known and more understandable title. In order to get the distinction and indicate the tone of the book one may consider that *divining* is the broader term, including not only *dowsing,* which is regarded by the authors as a psychological phenomenon and not explainable by physical theories, but also the use of rods for divination, such rods or sticks held to be possessed by a spirit or deity, or to be affected by exhalations or vapors, or by some occult influence parallel to physical forces such as magnetism or mass attractions, etc., etc.

The authors hold that "there exists a large mass of indisputable evidence proving that it is possible to find water, oil, metallic ores, coal, hidden objects, and so forth, by means of the rod." They conclude that "the evidence for the success of 'dowsing' as a practical art is very strong—and there seems to be an unexplained residuum when all possible deductions have been made."

The book is largely devoted to a recital of successes in the prediction of finding shallow water and is apparently regarded by the authors as proving the case for dowsing.

It is the view of the authors that the phenomena of dowsing are due to a suggestion being received in the dowser's subconsciousness by means of a sensibility as yet unknown to us (named by M. Richet, *Cryptesthesia*) and that the knowledge thus supernormally obtained can become conscious in several ways. The commonest method of revelation seems to be by subconscious automatic movement, such as those which provide the phenomena of automatic writings and of the planchette, generally expressed through the dipping of the dowsing rod.

It may come as a surprise to our more catholic minded geologists who dismiss 'divining' in all of its forms as a 'pestilent heresy,' to find that it is of great antiquity, and that the votaries of 'divination' are not all ignorant men or charlatans, but that there are occasional educated men

who sincerely, if perhaps mistakenly, believe that they possess powers of divination.

Your reviewer must confess that he has always had a sneaking fondness for these easy shortcuts in prospecting, and that he has wasted much time in investigating and testing various forms of divining rods or their equivalent. Even with this easy pre-disposition to believe, however, he has not yet met with a dowser or diviner who could secure results substantial enough to justify any faith in his abilities. The book under review, essentially an *ex parte* document—a brief for the diviner—does not convince. Almost any mining engineer or economic geologist of long experience could assemble, with little effort, a list of failures and disappointments much more imposing than the volume of successes put forward in this book.

E. De Golyer.

Die magnetische Verfahren der angewandten Geophysik (The Magnetic Methods of Applied Geophysics). By Hans Haalck. Mainka's *Sammlung geophysicalischer Schriften* No. 7. 150 pages, 61 figures, 3 plates. Gebrüder Bornträger, Berlin, 1927. Price 12 marks.

The contents of the book comprise: Introduction, an interesting brief statement of the scope of applied geophysics and of the place of magnetic methods; Fundamental Conceptions and Definitions; Terrestrial Magnetism, dealing with the observed data and mathematical analyses and the causes of the external and of the internal field; Areal Anomalies, their causes, theoretical relations between the embedded anomalous masses and the earth's field, the anomalies produced by masses of certain definite simple forms; Magnetic Variometers, observatory instruments, the older field instruments, the Haalck universal magnetic balance, the theory of magnetic measurements as illustrated by the use of the Haalck balance, the Schmidt-Lloyd "vertical" and "horizontal" variometers, the Königsberger variometer, the Kohlrausch variometers, the Bidlingmaier compass and other instruments; the Varying Magnetizibility of Different Types of Rocks and Minerals as a Cause of Local Anomalies, the magnetizability of various rocks and minerals, the methods of determining the susceptibility of samples of rock, the magnitude of terrestrial magnetic anomalies in relation to known causes (a list is given of 33 surveyed anomalies, the magnitude of the anomaly, its cause, and the reference to it in the literature, for each of the anomalies); the Operation of Practical Magnetic Surveys, the observations, the calculation of the results, the physical and geologic conclusions, Examples of Magnetic Anomalies, Kursk as an example of a strong magnetic anomaly and the Wefensleben salt dome ridge as the example of a weak anomaly, magnetic measurements underground; Conclusion, the applicability of the magnetic methods of exploration.

An extensive bibliography is given, and throughout the text, reference is made to some 110 of the more important papers on the subject. A list of 50 additional papers of importance is appended.

The book gives a reasonably complete and comprehensive view of the applied magnetic method and yet is reasonably simple and elementary. From it the geologist, mining engineer, or layman, who knows little or nothing about terrestrial magnetism and who can read easy scientific German should be able readily to get an intelligent conception of the magnetic method of prospecting, although the layman in mathematical physics will have to take for granted many parts of the mathematics. The book will make an excellent textbook for the general student and for the beginning student of geophysics. The more advanced students of applied geophysics and the geologists who are confronted with the necessity of conducting a magnetic survey will find it a valuable reference book but will wish that many portions of it went more into detail and treated the subject at slightly greater length. The subject furthermore has been intentionally presented from the point of view of the physicist-geophysicist rather than from the point of view of the geologist-geophysicist. The reader finds this book a decidedly welcome addition to his library on applied geophysics, and is glad to recommend it.

DONALD C. BARTON.

HOUSTON, TEXAS.

A Shorter Physical Geography. BY EMMANUEL DE MARTONNE; translated by E. D. LABORDE. 338 pages, 97 figs. Alfred A. Knopf, New York, 1928.

This translation is a welcome addition to our literature of geography, for it comes from the pen of the leading exponent of physical geography in France, and the translator has preserved the author's clarity of expression; it is written in delightful English. The introduction, dealing with the terrestrial globe, the atmosphere, crust, and hydrosphere, is followed by four parts. Part I. concerns climate, and is the clearest exposition of climate and weather that the reviewer has read. Part II., Hydrography, deals with the oceans, seas, lakes, and rivers. Part III., under the heading of Surface Relief, presents in an interesting manner the influences on topography of river erosion, geology, volcanism, tectonics, glaciation, deserts and coasts. The geographical rather than the geological features are emphasized. Under Part IV., Biogeography, the author takes up the distribution of plants, animals, and man. Paragraphs at the end of each part give suggestions for exercises and further study.

The treatment of the subject matter is essentially from the physical viewpoint, but so cleverly is the human side of geography interwoven, that the reader is always conscious of the control of the earth's features

over the economic and social life of man. It is a book well adapted for the use of elementary courses in Physical Geography, and can be read with profit and pleasure by the lay reader.

ALAN BATEMAN.

Undersøkelser over Lersedimenter. (Investigations concerning sedimentary clays.) Beretning om Nordiske Jordbrugsforskeres Kongres i Oslo, 1926. By V. M. GOLDSCHMIDT, 4.–7. Hefte.

The investigations whose results are presented in this paper were performed by Prof. Goldschmidt and co-workers in the Mineralogical Institute of the University of Oslo. The samples are Norwegian clays and include materials with widely different geological and technological characteristics. The term "composition of a clay" includes: (*A*) Chemical composition; (*B*) Mineralogical composition; and (*C*) Mechanical composition (grain-size.)

Chemically, the Norwegian clays can be divided into several groups, as for instance, typical Ostland clays, Vestland clays, Trondelags clays, etc. None of them contains a high percentage of kaolinite. They consist essentially of finely divided constituents of the bedrock (result of micro-petrographical investigations); hence their composition differs according to the character of the rocks from which they were derived. Thus the Trondelag clays are distinguished by a high content of mineral constituents rich in Mg (chlorite and hornblende), due to the presence within their area, of Cambro-Silurian eruptive rocks.

In order to express the chemical characteristics of the different clays, the average Al_2O_3/MgO ratio by weight was computed, giving the following results:

	Average.	Minimum.	Maximum.
32 clay samples from Trondelag, Romsdal Nordland.	3.6	2.7	4.7
15 clay samples from Vestland and Sorland.....	5.7	3.6	9.5
31 clay samples from Ostland.....	6.1	4.8	9.0

A high Mg-content usually indicates that the clay was derived from very old rocks, (except some from younger dolomitic shales). Utilizing these and similar relations, sedimentary petrographic evidence was obtained for Cambro-Silurian volcanic activities in Western and Northern Norway.

In determining the mineralogical composition of the clays by chemical analysis, the investigators had to deal with two sources of error:

(1) The chemical composition of the finest constituents of the clays

is not always identical with the composition of the rock-constituents of which they were formed. For example, instead of biotite, the finest clay fractions contain Chlorite, Sericite and other decomposition products.

(2) No account can be taken of the amorphous clay-constituent, which, however, is always small. Yet some of the iron always occurs in amorphous combinations.

Roves obtained the following data:

Locality.	Chlorite %.	Muscovite %.	Potassium-Feldspar.	Plagioclase.	Epidote %.	Hornblende %.	Quartz %.
Gudeberg....	8.46	19.22	11.66	16.12	1.61	4.81	30.00
Hoelstad....	6.12	18.90	8.28	20.05	2.00	6.77	29.37
Helle.....	8.59	3.41	23.30	31.25	4.69	9.14	14.36
Gravern.....	9.83	16.10	13.68	17.53	3.51	1.02	26.46
Tangen.....	16.29	9.60	12.98	24.16	4.83	1.18	24.03
Trana.....	9.24	14.28	4.73	22.10	4.42	6.78	28.83

With reference to their shape, the clay-constituents are described as: (1) flaky (scale-like; mica, chlorite, talc.); (2) elongated prismatic (hornblende, pyrogene, epidote, etc.); and (3) granular (bulky, more equidimensional; quartz, feldspar, apatite, ilmenite, rutile, limonite). The granular constituents make the clay sandy, dry, and short; the scale-like ones make it sticky, or plastic.

The following table shows the relation between the three constituents for different clays, according to Roves:

	Ostland Clays.			Vestland Clays.		Trondelag Clays.	
	Bratsberg.	Hoelstad.	Gudeberg.	Helle.	Gravern.	Trana.	Tangen.
Flaky minerals.....	17.20	25.02	27.68	12.00	25.93	23.52	25.89
Elongated shapes.....	6.59	8.77	6.42	13.83	4.53	11.20	9.01
Bulky constituents.....	67.36	64.36	63.35	72.67	67.66	60.74	66.39

The characteristic properties of the clays were originally ascribed to the amorphous clay constituents (products of rock weathering.) In order to determine the quantity of amorphous material, different clays were repeatedly treated with weak boiling acids, but without success.

The application of roentgenographic methods (Hadding) still presents considerable difficulties on account of the complex nature of the clays

In order to investigate the mineralogical composition of the clays, a study was first of all made of various factors which influence the results obtained by mechanical analysis, particularly of the effect of the shape of the grains on the velocity of settling (tests with powdered biotite). To perform the mechanical analysis, Grenness' pelometer was used. The results showed that the finest soil fractions contain a higher percentage of flaky minerals.

A study was also made of the arrangement of the scale-like particles by microscopic examination of clay specimens dried for a couple of hours at a temperature of 500–550° C. It was found that the flaky particles are arranged more or less parallel to each other and also that even the submicroscopic matrix of the clay contains a high percentage of flaky particles. This parallel arrangement may be one of the factors that accounts for the considerable decrease of cohesion in the clay upon kneading.

For a long time it was believed that the clay properties (consistency, stickiness, plasticity, water-holding capacity, etc.) were due to specific substances called "soil colloids." However, it was observed by Atterberg that certain minerals exhibit in a finely ground state all the characteristic properties of the clays, provided the particles are flaky. But in contrast to Atterberg's opinion, biotite is not one of the main constituents of the Scandinavian clays; its place is taken by muscovite and by the decomposition products of biotite.

An investigation of the causal relations which may exist between the scale-like shape of the particles of clays and the characteristic properties of the clays has led to the following conclusions: The scale-like minerals consist of consecutive layers of positive and negative ions. The cleavage planes are formed by particularly polarizable ions of which all are either positive or negative. The presence of these ions produces an electric field of considerable intensity. On the other hand, the water-molecules are dipolar. Hence, as soon as they enter the electric field of a cleavage surface they arrange themselves in a lawful manner. It is believed that the cohesion, plasticity and other characteristic properties of the clays are essentially due to the orientation of the water molecules within the electric field of the cleavage surfaces. If replacing the water by a liquid whose molecules are not bipolar, (tetrachlorcarbon), the clay mixture fails to exhibit the clay properties. On the other hand, if using as a substitute for the water another liquid with dipolar molecules (*e.g.*, SO_2 or NH_3 at low temperature) the clay properties persist. The interaction between the water and the cleavage planes is greatly intensified by the fact that the scale-like particles dominate in the finest fraction of the clays. The investigators believe that the water capacity of the clays is also connected with the polarization effects.

The investigations explain, among others, the intimate relation between the physical properties of the clays and the ion-concentration. In mortars and in cements, similar conditions may prevail.

Summary.—The characteristic properties of the clays are caused by two factors, of which both are essential: (1) A polarizing mineral (kaolin, mica, chlorite, talcum and others); (2) an interstitial liquid whose molecules can be polarized.

The most characteristic and most important component of the clay is the polarized water.

MASS. INST. OF TECHNOLOGY, CAMBRIDGE, MASS. CH. TERZAGHI,

The United States of America. Studies in Physical, Regional, Industrial and Human Geography. By ALBERT P. BRIGHAM. 308 pp. Oxford Univ. Press, London and New York, 1927. Price, $3.00.

This book is based on a course of lectures given by Professor Brigham of Colgate University in London in 1924. The author states it is not a geography of the United States but a series of studies of important phases of American geography. It starts out with a brief and excellent review of the physical growth of the country, and in Chapter II. is given in 25 pages a concise description of the physiographic provinces. The remaining chapters consider climate and population, natural resources, manufacture, transportation, commerce, education, and tradition, ending with a statistical appendix.

The book is entertainingly written in simple language for the general reader or for students, and contains in compact form a mass of interesting studies. It is finely printed on the high standards of the Oxford Press.

ALAN BATEMAN.

Geology and Natural Resources of Colorado. By RUSSELL D. GEORGE. University of Colorado Semicentennial Series 1877–1927. University of Colorado, Boulder, Colo., 1927. Pp. xv + 228. Maps, and plates. Price $2.00.

The University of Colorado is celebrating its Semicentennial by the publication of a series of 5 volumes of which this is the first, and very properly so, since it describes the setting for the phenomena and events discussed in the other 4 volumes. In it the author has collected the main facts concerning the geology, mineralogy, and physiography and those descriptive of the water, soil and pasture resources of the state, and has done his work well. The chapter on metals and metal mining (pp. 86–127) is particularly interesting, as it gives a summary of the geology of the important ore producing districts, which though concise is nevertheless explicit, in that it gives a satisfactory description of the events, so

far as they are known, that resulted in the deposition of the ore in each district, without burdening his account with a load of statements of irrelevant facts.

The book contains eight (8) sketch maps and fifteen (15) plates.

W. S. B.

Geology of Mongolia. By CHARLES P. BERKEY and FREDERICK K. MORRIS. Pp. xxxi, 475, 43 pl., 161 figs., 6 maps, index. Natural History of Central Asia, vol. II., Amer. Museum of Nat. History. G. P. Putnam's Sons, New York, 1927 (1928). Price, $10.00.

This is the first book to appear of a forthcoming series on the Central Asiatic Expeditions under the leadership of Roy Chapman Andrews. This volume deals with the geological studies made by the authors in 1921, 1922 and 1923; the results of the 1925 expedition will appear in Volume III. Five thousand miles of traverses in Central Mongolia furnished the material for this volume. It is assembled in four parts: Part I. is an introduction to the geological objectives, a review of former explorations, and methods of work; Part II. is a detailed description of the traverses and observations along the route; Part III. is a study of special localities where detailed work was done; Part IV. summarizes the great mass of data, and is the part of most general interest. It is really a textbook on the geology of Mongolia, and treats of structure, physiography, stratigraphy, climates, and geologic history. Here the authors draw together the various problems of geology raised in the field work and in their subsequent studies, and this part is an able contribution not only to the geology of Mongolia but to the larger geological features of Asia. The discussions of past climates and physiography are especially noteworthy, and the reader profits by the careful field work and broad vision of experienced and capable authors.

The text matter is clarified by a large number of clear diagrams and cross sections, and the handiwork of the junior author is evident in the many excellent sketches and block diagrams that illustrate physiographic features. The carefully chosen photographs add greatly to the discussions.

The authors are to be congratulated for their valuable work, and the publishers for a fine example of book-making. It is a book that should be in every geological library.

ALAN BATEMAN.

BOOKS RECEIVED

Aufgaben und Arbeitsweisen der Ölgeologie. By HANS HLAUSCHEK. Abhandl. zur prakt. Geologie, u. Bergw. Band 14. 112 pp. Wilhelm Knapp, Halle, Germany, 1928 (April). Price, 8 marks.

Concise treatment of oil field technology; geophysical investigation, drilling, extraction, recording, oil field waters. Bibliography.

Stars and Atoms. By A. S. EDDINGTON, Cambridge University. 127 pages, 11 figs. Yale University Press, New Haven, Conn., 1927. Reprinted, 1928 (April). Price, $2.00.

Material of three lectures before the British Association in Oxford, in 1926. Delightfully written story in simple language of the recent knowledge of the stars, by an authority.

Molding Sands of Pennsylvania. By R. W. STONE and American Foundrymen's Association. Pennsylvania Geol. Survey Bull. 11, Harrisburg, 1928 (April). 94 pp.

Tests; classification; origin; occurrence; locations.

Geography, Geology, and Mineral Resources of Part of Southeastern Idaho. By G. S. MANSFIELD. (Erroneously given in March-April number as G. S. Rogers.) With descriptions of Carboniferous and Triassic Fossils by G. H. GIRTY. 453 pp., 70 plates, 46 figures. U. S. Geol. Surv. Prof. Paper 152. Washington, 1927.

A comprehensive treatise of the geology of the Western phosphate reserve in Idaho.

Beiträge zur Kenntnis der Golderzlagerstätten Kolumbiens: Die Golderzgänge von Recreo. By W. RINTISCH. *Abhandl. z. prakt. Geol. u. Bergw.*, Band. 16. 37 pp., 7 figs., 6 pl. Wilhelm Knappe, Halle, Germany, (May) 1928. Price 3,50 marks.

Interesting account of the regional geology, gold deposits and their origin, mineralogy, and placers.

The Fire Clays of Pennsylvania. By J. B. SHAW. 69 pp. Top. and Geol. Surv. of Penn. Bull. No. 10, 1928 (April).

Partial report. Tests, classification, locations. Appendix on fire brick materials, by G. H. Ashley.

Power Capacity and Production in the United States. By C. R. DAUGHERTY, A. H. HORTON and R. W. DAVENPORT. 210 pp. U. S. G. S. Water Supply Paper 579, 1928 (May),

Development of prime movers; developed and potential water power; production and growth in the United States.

Geomorphology of Southwestern San Gabriel Mountains of California. By WILLIAM J. MILLER. Univ. of Cal. Publications, Vol. 17, No. 6, 1928 (May). 46 pp.

Orogeny, fault blocks, erosion, glaciation, recent deposition.

Geophysical Methods of Prospecting. By A. S. EVE and D. A. KEYS. 26 pp. U. S. Bur. of Mines, Tech. Paper 420, 1927. Price, 10 cts.

A brief and elementary account of the principles involved.

The Stratigraphy of the Pennsylvania System in Nebraska. By G. E. CONDRA. Nebraska Geol. Survey Bull. 1, 2d ser. 292 pp., 6 plates, 38 figs. Univ. of Nebraska Press, 1927.

A general detailed scientific description of the stratigraphy of the oldest system of rocks in the State.

Southern California Geology and Los Angeles Earthquakes. By R. T. HILL. 232 pp., illus. So. Cal. Acad. of Sci., Los Angeles, 1928 (May). Price, $5.00.

A refutation of the statement that Los Angeles is menaced by earthquakes.

Geology and Economic Resources of the St. Peter Sandstone of Illinois. By J. E. LAMAR. 175 pp., 43 figs. Illinois State Geol. Surv. Bull. 53, Urbana, Ill., 1928 (May).

Comprehensive; complete on uses and specifications of sand.

Mining Industry of Idaho for 1927. By STEWART CAMPBELL. 280 pp., index. 1928 (May).

SCIENTIFIC NOTES AND NEWS

W. S. Bayley has been made head of the department of geology at the University of Illinois, Urbana, Ill. T. T. Quirke, formerly chairman of geology, will continue at the University as professor of geology. He will spend the summer with the Geol. Survey of Canada near Parry Sound, Ontario.

Charles W. Wright, who for many years has been engaged in mining in Sardinia and northern Italy, and returned to this country last year, has been made chief engineer of the Mining Division of the U. S. Bureau of Mines at Washington.

Sydney H. Ball, of Rogers, Mayer & Ball, of New York City, has been spending a month in Canada on professional business.

Frederick G. Clapp is engaged in a reconnaissance of the oil fields of southern and western Persia and the fields of Iraq.

L. C. Graton has left South Africa for Mysore, India.

D. D. Irwin, general superintendent of the Copper Queen Branch, Phelps Dodge Corp., Bisbee, Arizona, has been chosen as general manager of the Roan Antelope Mine in Northern Rhodesia, South Africa. He will leave Bisbee June 1, spend some time in New Haven and New York, then proceed to London, and will reach Rhodesia in early September.

P. G. Nutting, of the U. S. Geological Survey, is in Bradford, Pa., studying problems connected with the recovery of petroleum.

Cyril W. Knight, formerly of the Ontario Geological Survey and recently with the Nipissing Mining Company, has organized a company for exploration work in Patricia, northern Manitoba, and Northwest Territory mining fields.

Chester K. Wentworth has been appointed associate professor of geology at Washington University, St. Louis, Mo., and will take up his duties in September. During the summer he will continue the examination of dam-sites in the Tennessee River basin.

C. H. Dane is making coal examinations for the U. S. Geological Survey in northwestern New Mexico.

W. D. Johnston, Jr., has resigned his position in the New Mexico School of Mines to accept an appointment with the Ground Water Division of the U. S. Geological Survey.

H. H. Knox was in New York recently on his way from London to Australia.

E. G. Zies, of the Geophysical Laboratory at Washington, is to spend several months in the Dutch East Indies studying the gases and other volatile products, and E. T. Allen and C. N. Fenner are spending the summer in Yellowstone National Park studying the chemical and geological problems of the geysers and hot springs.

H. G. Ferguson, of the U. S. Geological Survey, gave a paper on the Gold-Quartz Veins of the Alleghany Region, California, before the Petrologists' Club in Washington in April.

H. D. Miser, E. F. Burchard and D. F. Hewett, of the U. S. Geological Survey, have gone to Woodstock, Va., to examine manganese deposits.

F. H. Moffit, of the U. S. Geological Survey, left in May for the Copper River region, Alaska, to study the geology and mineral resources.

B. L. Johnson, of the U. S. Bureau of Mines, is engaged in a study of the phosphates of the South.

A. C. Burrows, of the Ontario Department of Mines, is in charge of the examination of the zinc-lead-copper deposits of the Sudbury Basin.

Lucien Eaton, of the Cleveland-Cliffs Iron Company, Ishpeming, Mich., has returned after several months in Russia, where he has been examining iron mining properties in the Krivoi-Rog district, in the Ukraine.

Duncan Smith is spending six months in examining gold and tin prospects in East Africa for a French-Belgian group.

C. P. Ross, of the U. S. Geological Survey, is carrying on work in Idaho in the Bayhorse quadrangle.

Russell S. Knappen, of the Gypsy Oil Company, recently addressed the students in geology and mining engineering at the University of Kansas on geophysical prospecting.

A P. Coleman, professor of geology at the University of Toronto, is the recipient of the Favelle medal from the Royal Society of Canada for scientific research work.

E. S. Bieler, of McGill University, Montreal, Canada, is deputy director of a geophysical survey inaugurated in Australia by the Government and the Imperial Marketing Board, to increase ore reserves.

J. B. Read has been appointed professor of mining at the Colorado School of Mines.

H. W. Hoots has resigned from the U. S. Geological Survey and gone to Pasadena, Cal.

S. R. Capps, J. B. Mertie, Jr., R. H. Sargent, Gerald Fitzgerald, and R. K. Lynt, of the U. S. Geological Survey, are in Alaska engaged in field work. Mr. Capps and Mr. Fitzgerald are making geologic and topographic surveys in the Mount Spurr region.

George H. Garrey has recently been spending some time at the Piermont and Ruby Hill Apex properties near Ely, Nevada, and the Alto Mine, in the Patagonia district of Arizona.

Hiram W. Hixon has returned to the United States after an absence of four and a half years in Europe.

Francis A. Thomson, dean of the Idaho School of Mines, since 1917, has been made president of the Montana School of Mines, at Butte.

E. L. Bruce, of Queen's University, Kingston, Canada, is engaged in a geological survey for the Canadian National Railways of the country between the Flin Flon and Sheritt-Gordon properties in northern Manitoba.

Ellsworth Y. Dougherty is examining mining properties in Newfoundland. His address is Box E–5299, St. John's, Newfoundland.

A geological field conference was held in northwestern Arkansas May 12 and 13, under the auspices of the Department of Geology of the University of Arkansas. About fifty geologists were present, representing Arkansas, Kansas, Missouri, and Nebraska. Formations of late Mississipian and early Pennsylvania age were studied.

The Institution of Mining and Metallurgy, London, held a special meeting in Cornwall on May 22–24. Visits to the mines were included.

The United Verde Copper Company has established a microscopic laboratory at Clarkdale to utilize the microscope as an aid in ore dressing.

The Geological Society of America will hold its next meeting in New York City December 27–29, 1928, at the American Museum of Natural History and Columbia University. The nominations for officers for 1929 are: For president, Heinrich Ries; vice-presidents, W. S. Bayley, U. S. Grant, E. C. Case; councillors, H. F. Cleland and E. S. Moore.

The American Institute of Mining and Metallurgical Engineers will hold its fall meeting in Boston the last week in August. Following this there will be an excursion to Newfoundland, starting from Boston September 1 or 2 and returning two weeks later. The submarine Wabana Iron mines and the Bucans mine will be visited. A stop will be made en route at North Sidney, N. S., at the Dominion Coal Company mines and the plant of the British Empire Iron and Steel Company.